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ATTITUDE SEQUENCE FOR THE APOLLO 8 SPACECRAFT OPERATIONAL TRAJECTORY

Lunar Mission Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER

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PROJECT APOLLO

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By Mission Design Section
TRW Systems Group

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SPACECRAFT OPERATIONAL TRAJECTORY

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1. SUMMARY AND INTRODUCTION

1.1 General

This document presents the operational attitude sequence for the C-prime lunar orbit mission. The spacecraft attitude data and event sequence contained in this report reflect current philosophy in areas pertinent to the development of the mission attitude timeline. This philosophy was formulated primarily through analysis and working group meetings with appropriate MSC and contractor personnel. The basic techniques and procedures as agreed upon through these discussions are subject to revision resulting from operational aspects of the mission attitude profile. Any such revisions will be published as addenda to this document.

The spacecraft operational attitude data are presented in the following format:

1. Discussion of the major attitude events occurring during the mission

2. Figures illustrating the attitude events

3. Mission attitude timeline indicating the chronological sequence of events (Table I). Event times for the mission were obtained from the Apollo 8 Preliminary Flight Plan, Reference 1.

4. Tabular data summarizing the pertinent parameters of interest (Table II)

1.2 Trajectory Profile

The spacecraft operational trajectory furnishing the state vector and ephemeris data for generating the required attitude data was obtained from the Lunar Mission Analysis Branch of MPAD-MSC. The trajectory was precision integrated on the Apollo Reference Mission Program Version ARM06. Launch date for the trajectory was 21 December 1968 with a launch azimuth of 72 degrees.

Major events in the mission include the launch to insertion into a 100-nautical mile altitude earth parking orbit. A Pacific injection on the second revolution in earth orbit initiates the translunar phase of the mission. The translunar and transearth phases are characterized by relatively short flight times of approximately 66 hours and 85 hours, respectively. The lunar orbit phase consists of ten revolutions in lunar orbit devoted primarily to optical navigation and photography assignments.

1.3 Attitude Data Generation

The attitude data required to analyze and define the various spacecraft attitude events were produced using the Apollo Mission Attitude Requirements (AMAR) Program. It should be noted that attitude maneuvers which reorient the spacecraft from an existing attitude are performed instantaneously in the AMAR simulation of the attitude event sequence. Maneuver times are shown for the applicable maneuvers in the cislunar portion of the timeline with the previous attitude carried through to the instantaneous initiation of the new orientation. The maneuver times are best estimates and are not intended to reflect actual reorientation procedures. Lunar orbit attitude maneuvers are shown at the initiation time for the reorientation since the operational maneuver procedures have not been defined for this phase of the mission.

1.4 Constraints

To facilitate discussion of the attitude event timeline, the primary spacecraft attitude constraints applicable to various phases or events in the mission are listed in this section.

1.4.1 Earth parking orbit constraints. -

1. The CSM attitude must provide continuous tracking, command, telemetry, and voice capabilities when line of sight to a MSFN station exists.

2. CSM gimbal lock must be avoided. For this mission, gimbal lock has been defined as an angle of 45 degrees or less between the outer gimbal axis and the inner gimbal axis.

1.4.2 Cislunar constraints. -

1. Continuous S-IVB tracking and telemetry are required for a 10-minute period within the first 20 minutes after TLI cutoff.

2. S-IVB tracking, telemetry and command and CSM tracking, telemetry and voice are required during the S-IVB/CSM separation maneuver.

3. Telemetry is required from the S-IVB for a minimum of 10 minutes following S-IVB/CSM separation.

4. CSM tracking, command, telemetry, and voice are required for one hour following S-IVB/CSM separation.

5. CSM gimbal lock must be avoided.

6. The S-IVB attitude at S-IVB/CSM separation must provide illumination of the forward end of the S-IVB to simulate the lighting for the LM extraction maneuver.

7. For midcourse correction (MCC) maneuvers, continuous CSM command, telemetry, and voice are required for the 1-hour period beginning 30 minutes before the MCC.

8. The maximum duration of a continuous attitude hold for the CSM cannot exceed 1 hour. This is a fracture mechanics limit imposed by the RCS propellant tanks in a hot environment.

9. The ratio of thermal control time to attitude hold time should be at least 5 to 1.

10. For IMU alignments, the CSM inertial attitude must provide a suitable starfield for the optics field of view.

11. For IMU alignments, the sun line of sight must not be within 15 degrees of the sextant (SXT) boresight nor within 55 degrees of the scanning telescope (SCT).

12. For cislunar optical navigation, the sun line of sight must not be within 10 degrees of the landmark line of sight nor within 15 degrees of the star line of sight for the SXT.

13. For periods of passive thermal control (PTC), the CSM should be oriented as near broadside to the earth as possible to optimize omni antenna-earth communications.

1.4.3 Lunar orbit constraints. - There are no unique CSM attitude constraints for the lunar orbit phase of the mission. Attitude requirements pertaining to cislunar optical navigation, IMU alignments, gimbal lock avoidance, and MSFN communications must be satisfied by appropriate attitude orientations in lunar orbit. Violation of any of these constraints (usually communications) to meet mission objectives are pointed out in the discussion.

2. SYMBOLS

ALT	altitude
ARM06	Apollo Reference Mission Program Version ARM06
AMAR	Apollo Mission Attitude Requirements Program
AOS	acquisition of signal
CM	command module
CSM	command and service module
EMP	earth-moon plane
g.e.t.	ground elapsed time (hr:min:sec)
IGA	inner gimbal angle
IMU	inertial measurement unit
LAT	selenographic latitude
LM	lunar module
LMAB	Lunar Mission Analysis Branch
LOI-1	first lunar orbit insertion burn
LOI-2	lunar orbit circularization burn
LON	selenographic longitude
LOS	loss of signal
MCC	midcourse correction
MGA	middle gimbal angle
MPAD-MSC	Mission Planning and Analysis Division-Manned Spacecraft Center
MSFN	Manned Space Flight Network
OGA	outer gimbal angle
PTC	passive thermal control
RCS	reaction control system

REFSMMAT	reference to stable member coordinate transformation matrix
SCT	scanning telescope
SDA	shaft drive axis
SEH	star/earth horizon
SEL	star/earth landmark
SLA	spacecraft LM adapter
SLH	star/lunar horizon
SLL	star/lunar landmark
SM	service module
SPS	service propulsion system
SXT	sextant
S-IVB	third stage of Saturn V vehicle
TE	transearth
TEI	transearth injection
TL	translunar
TLI	translunar injection
ΔV	velocity increment

3. EARTH ORBIT PHASE

The S-IVB/SLA/CSM configuration is inserted into a 100-nautical mile altitude circular parking orbit by the Saturn V booster at 00:11:20 g.e.t. The burnout attitude is held inertially fixed for 15 seconds after termination of the insertion burn. Following this hold, the S-IVB attitude control system positions the S-IVB (and CSM) X-axis along the local horizontal in the direction of motion. The CSM Z-axis is in the trajectory plane with the crew heads down. An S-IVB orbital pitch rate is then initiated in order to maintain this alignment locally fixed during the earth orbit phase of the mission. This attitude assures communication coverage during passes over MSFN stations. During the second revolution in earth parking orbit, the S-IVB will orient to the TLI burn attitude. The burn is performed under attitude control by the S-IVB guidance and control systems.

It should be noted at this point that the IMU gimbal angle data shown in the tables are based on the prelaunch REFSMMAT until the IMU is realigned prior to the last TL MCC. Gimbal angle measurements after this realignment will reflect the new IMU attitude reference as will be discussed in the appropriate section. Table III lists the direction cosines corresponding to the three IMU REFSMMAT alignments which are unique for the given launch date and launch azimuth.

Table II(a) lists the spacecraft position and attitude data for the earth orbit phase of the mission.

4. TRANSLUNAR PHASE

This section contains a brief description of major attitude events in the translunar phase of the mission. Most of these events, as noted in their descriptions are also common to the transearth phase of the mission. Those events occurring only in the transearth phase will be described in Section 6. A graphical presentation of the major cislunar events is given in Figure 1. Spacecraft look angles and IMU gimbal angles for the translunar phase are given in Table II(b).

4.1 Post-TLI Sequence of Events

Following the termination of the TLI burn at 02:55:43 g.e.t., the burnout attitude is fixed inertially for 20 seconds. At the end of this time period, the local horizontal mode is again established by the S-IVB attitude control system for MSFN post-TLI checkout. Fifteen minutes after TLI cutoff, the S-IVB orients to the S-IVB/CSM separation attitude. Primary considerations involved in defining the separation attitude are communications, gimbal lock, and lighting on the forward end of the S-IVB. The lighting constraint is to evaluate illumination of the LM docking tunnel for later missions having the LM onboard. The orientation thus consists of a pitch maneuver to point the SLA generally towards the sun and a roll maneuver for communications. The separation attitude is held inertially fixed until a separation distance of about 50 feet is achieved between the S-IVB and CSM. The CSM is then pitched through 180 degrees to face the S-IVB. This attitude provides visual observation of the S-IVB and MSFN communications. A roll maneuver of minus 60 degrees is executed from this attitude for the proper docking alignment. The CSM station-keeps at this attitude for approximately 13 minutes and then orients to the evasive maneuver attitude. This attitude consists of the CSM X-axis being aligned along the negative position vector. The CSM minus Z-axis is oriented in the direction of motion and in the trajectory plane. The purpose of the orientation is to provide visual monitoring of the S-IVB venting and a nominal thrusting alignment for an RCS burn to avoid S-IVB recontact.

The evasive maneuver attitude is held inertially fixed until 05:07:43 g.e.t., at which time the CSM will be positioned to observe the S-IVB slingshot trajectory. The CSM attitude for this event aligns the CSM X-axis 18 degrees below the negative velocity vector. Communications coverage is optimized by minimizing the angle between the negative position vector and the S-band antenna boom. The CSM monitoring attitude is fixed inertially for approximately one hour.

The post-TLI sequence of events is illustrated in Figure 2. Numerical data for the post-TLI sequence were obtained from Reference 2.

4.2 Navigation Sightings

During the cislunar phase of the mission, optical navigation will be performed to determine onboard navigation capability. These sightings occur throughout the mission as noted in the tabular data. The various types of cislunar navigation sightings are

1. Star/earth horizon sightings - optical sightings taken on a reference star and the lighted earth horizon

2. Star/earth landmark sightings - optical sightings taken on a reference star and a known or unknown earth landmark

3. Star/lunar horizon sightings - optical sightings taken on a reference star and the lighted lunar horizon

4. Star/lunar landmark sightings - optical sightings taken on a reference star and a known or unknown lunar landmark

The CSM orientation for optical sightings must consider requirements for communications and avoidance of gimbal lock as well as the optical pointing requirements. Sightings involving the earth horizon or landmarks can usually be accomplished at an attitude satisfying these requirements. This is caused by the fact that the CSM optics and S-band antenna are only 48 degrees apart and point in the same general direction. Lunar navigation sightings, however, produce attitudes inconsistent with S-band communications requirements for the same reason. Figure 3 illustrates the geometrical situation for both earth and lunar navigation sightings.

4.3 Passive Thermal Control

A nominal thermal environment is provided during the cislunar phase for temperature-critical spacecraft components by the passive thermal control (PTC) mode. The CSM PTC orientation consists of aligning the CSM X-axis normal to the solar vector and rolling about the X-axis at two revolutions per hour. Attitude control is maintained in wide angle deadband (± 5 degrees) in pitch and yaw when the PTC attitude is established. Roll axis control may then either be maintained or disabled. For simulation purposes in this timeline, the X-axis pointing was fixed.

The PTC orientations have also been optimized for omni antenna coverage by positioning the X-axis as broadside to the earth as possible without violating the middle gimbal angle constraint. Figure 4 shows this orientation procedure.

It may be noted by referring to the tabular data that the lunar mission rule requiring a 5 to 1 ratio of PTC time to attitude-hold time is not satisfied for the major portion of this timeline. This is due primarily to the short translunar and transearth flight times. During the mission, the thermal control requirement could be met to some degree by roll maneuvers to reorient the spacecraft between star sightings.

4.4 IMU Alignments

Prior to the midcourse correction (MCC) maneuvers, lunar orbit insertion, and entry, the crew will realign the IMU to preclude drift errors in targeting for these events.

The CSM cislunar IMU alignment attitude is involved primarily with obtaining a suitable starfield for the CSM optics. For generation of this attitude timeline, it has been assumed that the attitude preceding each IMU alignment (with the exception of the pre-LOI alignment) which is usually a navigation sighting attitude is acceptable for performing the alignment. This assumption implies that a suitable starfield should be available with the existing attitude. In the event of earth or lunar occlusion at this attitude, a roll maneuver could be employed to obtain a clear optics field of view.

4.5 Midcourse Corrections

At specified times during the translunar and transearth phase of the mission, the ground will determine by state vector propagation if the current trajectory will satisfy desired end conditions. If the trajectory is deemed unacceptable, a midcourse correction maneuver will be performed by either the SPS or the RCS.

Since the MCC attitude is dependent on the type of adjustment maneuver required, this attitude cannot be described prior to the mission. This timeline has, therefore, assumed each MCC occurs in the previous attitude (IMU alignment) with a ΔV for the maneuver of zero.

4.6 Pre-LOI Sequence of Events

The IMU alignment prior to the last translunar MCC will align the IMU to the LOI-2 REFSMMAT. The IMU alignment is to provide the crew with gimbal angles of 0, 180, 0 (roll, pitch, yaw) at the start of the LOI-2 burn.

After the time for the last translunar MCC, the CSM is aligned to the PTC orientation. Approximately 5 hours later, another IMU alignment is performed, after which the PTC mode is resumed. Approximately 1-1/2 hours later, the CSM is oriented to the LOI-1 burn attitude, and another IMU alignment is performed. This attitude is held inertially fixed through the LOI-1 burn.

5. LUNAR ORBIT PHASE

A detailed description of each revolution is included for the lunar orbit portion of the attitude sequence because of the many and varied events which occur. Instantaneous maneuvers have been shown because operational procedures are not as yet defined. The mission time of the maneuver should be regarded as the time of initiation of the attitude maneuver. A sufficient time interval has been allowed between the instantaneous maneuver and the following event for which the maneuver was required. Table II(c) presents the spacecraft positional and attitude data for the lunar orbit phase of the mission.

5.1 First Revolution (Figure 5)

The sequence of significant events that occur during the first revolution is as follows:

1. First lunar orbit insertion (LOI-1) burn
2. Acquisition of MSFN line of sight
3. Enter darkness
4. IMU realignment
5. Loss of MSFN line of sight
6. Enter sunlight
7. Lunar observation and photography

The LOI-1 burn deboosts the CSM from the cislunar trajectory into a 60-nautical mile by 170-nautical mile elliptical parking orbit. The burn is performed with the CSM in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The LOI-1 burn attitude is held inertially fixed until immediately prior to acquisition of MSFN line of sight. The CSM is then rolled 180 degrees to establish S-band communications. The resulting attitude is held inertially fixed until loss of MSFN line of-sight. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment which occurs immediately after the CSM enters darkness. At the loss of MSFN line-of-sight, the CSM is maneuvered to an attitude which allows lunar visual observation and photography. The vehicle attitude, with respect to the local horizontal orientation, is a pitch of minus 45 degrees and a roll of 180 degrees. This attitude is held locally fixed through the completion of the first revolution.

This attitude sequence allows S-band communications from the acquisition of MSFN line of-sight to the loss of MSFN line of-sight.

5.2 Second Revolution (Figure 6)

The sequence of significant events that occur during the second revolution is as follows:

1. Lunar observation and photography
2. Acquisition of MSFN line of sight
3. Enter darkness
4. IMU realignment
5. Loss of MSFN line of sight
6. Enter sunlight

At the completion of the first revolution, the CSM is in a locally fixed attitude which allows lunar visual observation and photography. The local attitude hold is maintained until approximately 7 minutes prior to the CSM entering into darkness. At this time, the local attitude hold is terminated, and the existing vehicle attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment which occurs about 5 minutes after the CSM enters darkness. Approximately 8 minutes prior to the loss of MSFN line of sight, the inertial attitude hold is terminated, and the CSM is maneuvered to the circularization (LOI-2) burn attitude. The CSM is first maneuvered to an attitude which is rolled 180 degrees from the burn attitude to allow S-band communications. After the loss of MSFN line of sight, the CSM is rolled minus 180 degrees into the circularization burn attitude. This attitude is held inertially fixed through the remainder of the second revolution.

This attitude sequence allows S-band communications from the acquisition of MSFN line of sight to the loss of MSFN line of sight.

5.3 Third Revolution (Figure 7)

The sequence of significant events that occur during the third revolution is as follows:

1. Circularization burn
2. Landmark familiarization
3. Acquisition of MSFN line of sight
4. Pseudo landing site landmark familiarization and photography
5. Enter darkness

6. IMU realignment

7. Loss of MSFN line of sight

8. Enter sunlight

9. Orbital navigation photography

Immediately following the start of the third revolution, the circularization burn is performed. The circularization burn transforms the initial elliptical parking orbit into a 60-nautical mile circular orbit. The burn is performed with the CSM in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. After the burn, the CSM burn attitude is held inertially fixed for approximately 10 minutes. The CSM is then maneuvered to an attitude which allows landmark familiarization and photography. In this exercise, the CSM X-axis cameras are given the same pointing profile that the CSM shaft drive axis (SDA) will have during landmark sightings. The vehicle attitude, with respect to the local horizontal orientation, is a pitch of minus 52.5 degrees and a roll of 180 degrees. This attitude is held locally fixed until the CSM cameras become pointed at the pseudo landing site landmark (Table IV). A manual pitch rate is then initiated to keep the cameras pointed at the landmark. Approximately 1.5 minutes after the CSM passes the closest point of approach to the landmark, the pitch rate is terminated, and the vehicle is pitched minus 70 degrees. The resulting attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 7 minutes after the CSM enters darkness. The inertial attitude hold is maintained until approximately 19 minutes before the CSM enters sunlight. The inertial attitude hold is then terminated, and the CSM is maneuvered to an attitude which allows orbital navigation photography. The vehicle attitude, with respect to the local horizontal orientation, is a pitch of minus 90 degrees and a roll of 180 degrees. This attitude is held locally fixed while the CSM X-axis cameras perform vertical stereo photography. The CSM windows are oriented away from the sun to allow better photography. This attitude is held locally fixed through the completion of the third revolution.

Except for a small period of time during the photography of the pseudo landing site landmark, this attitude sequence allows S-band communications from the acquisition of MSFN line of sight to the maneuver to the orbital navigation photography attitude.

5.4 Fourth Revolution (Figure 8)

The sequence of significant events that occur during the fourth revolution is as follows:

1. Orbital navigation photography

2. Acquisition of MSFN line of sight

3. Landmark lighting evaluation

4. Enter darkness

5. IMU realignment

6. Loss of MSFN line of sight

7. Enter sunlight

At the start of the fourth revolution, the CSM is in the locally fixed orbital navigation photography attitude. The local attitude hold is maintained, and the vehicle is rolled minus 180 degrees as it passes over the sub-solar point to orient the windows away from the sun. Approximately 13 minutes before the CSM passes the closest point of approach to the pseudo landing site landmark, the CSM is maneuvered to the initial tracking attitude for the Mode III type landmark sighting attitude sequence (Figure 9). The attitude at the beginning of a Mode III type tracking sequence, with respect to the local horizontal orientation, is a pitch of 5 degrees. This attitude is maintained locally fixed until the CSM is about 3 minutes from the closest point of approach to the landmark. The CSM is then given a minus 0.3-degree per second pitch rate to keep the landmark in the optics field of coverage throughout the tracking period. Approximately 1.5 minutes after the CSM passes the closest point of approach to the landmark, the pitch rate is terminated. This Mode III type tracking sequence is used for the landmark lighting evaluation of the pseudo landing site landmark. After the tracking sequence is terminated, the CSM is rolled 180 degrees to gain S-band communications, and the resulting attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 9 minutes after the CSM enters darkness. About 7 minutes before the CSM enters sunlight, the inertial attitude hold is terminated, and the CSM is maneuvered to the initial landmark tracking attitude for a Mode III type landmark sighting sequence, which occurs early in the fifth revolution on the second control point landmark (Table IV). The initial landmark sighting attitude, which is a pitch of 5 degrees with respect to the local horizontal orientation, is held locally fixed through the completion of the fourth revolution.

This attitude sequence allows S-band communications from the completion of the landmark evaluation to the loss of MSFN line of sight.

5.5 Fifth Revolution (Figure 10)

The sequence of significant events that occur during the fifth revolution is as follows:

1. Landmark sighting on the second control point landmark

2. Acquisition of MSFN line of sight

3. Landmark sighting on the pseudo landing site landmark

4. Enter darkness

5. IMU realignment

6. Loss of MSFN line of sight

7. Enter sunlight

At the beginning of the fifth revolution, the CSM is in the locally fixed initial landmark tracking attitude. A Mode III type landmark sighting sequence is performed on the second control point landmark (Table IV), and then the vehicle is maneuvered back to the initial landmark tracking attitude for a Mode III type landmark sighting sequence on the pseudo landing site landmark. After the completion of the sighting sequence on the pseudo landing site landmark, the CSM is rolled 180 degrees to gain S-band communications, and the resulting attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 15 minutes after the CSM enters darkness. About the time the CSM enters sunlight, the inertial attitude hold is terminated, and the CSM is maneuvered to the initial landmark tracking attitude for a Mode III type landmark sighting sequence, which occurs early in the sixth revolution on the second control point landmark. The landmark sighting attitude is held locally fixed through the completion of the fifth revolution.

This attitude sequence allows S-band communications from the completion of the landmark sighting sequence on the pseudo landing site landmark to the loss of MSFN line of sight.

5.6 Sixth Revolution (Figure 11)

The sequence of significant events that occur during the sixth revolution is as follows:

1. Landmark sighting on the second control point landmark

2. Acquisition of MSFN line of sight

3. Landmark sighting on the pseudo landing site landmark

4. Enter darkness

5. IMU realignment

6. Loss of MSFN line of sight

7. Enter sunlight

8. Landmark sighting on the first control point landmark

At the beginning of the sixth revolution, the CSM is in the locally fixed initial landmark tracking attitude. A Mode III type landmark sighting sequence is performed on the second control point landmark, and then the vehicle is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence on the pseudo landing site landmark. After the completion of the sighting sequence on the pseudo landing site landmark, the CSM is rolled 180 degrees to gain S-band communications, and the resulting attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 13 minutes after the CSM enters darkness. About 5 minutes before the CSM enters sunlight, the inertial attitude hold is terminated, and the CSM is maneuvered to the initial landmark tracking attitude for a Mode III type landmark sighting sequence on the first control point landmark (Table IV). After the completion of the sighting sequence, the vehicle is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence, which occurs early in the seventh revolution on the second control point landmark. The inital landmark sighting attitude is held locally fixed through the completion of the sixth revolution.

This attitude sequence allows S-band communications from the completion of the landmark sighting sequence on the pseudo landing site landmark to the loss of MSFN line of sight.

5.7 Seventh Revolution (Figure 12)

The sequence of significant events that occur during the seventh revolution is as follows:

1. Landmark sighting on the second control point landmark
2. Acquisition of MSFN line of sight
3. Landmark sighting on the third control point landmark
4. Landmark sighting on the pseudo landing site landmark
5. Enter darkness
6. IMU realignment
7. Loss of MSFN line of sight
8. Enter sunlight
9. Landmark sighting on the first control point landmark

At the beginning of the seventh revolution, the CSM is in the locally fixed initial landmark tracking attitude. A Mode III type landmark sighting sequence is performed on the second control point landmark, and then the vehicle is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence on the third

control point landmark (Table IV). Upon completion of the sighting on the third control point landmark, the CSM is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence on the pseudo landing site landmark. After the completion of the sighting sequence on the pseudo landing site landmark, the CSM is rolled 180 degrees to gain S-band communications, and the resulting attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 13 minutes after the CSM enters darkness. About 3 minutes before the CSM enters sunlight, the inertial attitude hold is terminated, and the CSM is maneuvered to the initial landmark tracking attitude for a Mode III type landmark sighting sequence on the first control point landmark. After the completion of the sighting sequence, the vehicle is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence, which occurs early in the eighth revolution on the second control point landmark. The initial landmark sighting attitude is held locally fixed through the completion of the seventh revolution.

This attitude sequence allows S-band communications from the completion of the landmark sighting sequence on the pseudo landing site landmark to the loss of MSFN line of sight.

5.8 Eighth Revolution (Figure 13)

The sequence of significant events that occur during the eighth revolution is as follows:

1. Landmark sighting on the second control point landmark
2. Acquisition of MSFN line of sight
3. Landmark sighting on the third control point landmark
4. Landmark sighting on the pseudo landing site landmark
5. Enter darkness
6. IMU realignment
7. Dark side and solar corona photography
8. Loss of MSFN line of sight
9. Orbital navigation photography (convergent stereo photography)
10. Enter sunlight

At the beginning of the eighth revolution, the CSM is in the locally fixed initial landmark tracking attitude. A Mode III type landmark sighting sequence is performed on the second control point landmark, and then the vehicle is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence on the third

control point landmark. Upon completion of the sighting on the third control point landmark, the CSM is maneuvered back to the locally fixed initial landmark tracking attitude for a Mode III type landmark sighting sequence on the pseudo landing site landmark. After the completion of the sighting sequence on the pseudo landing site landmark, the CSM is rolled 180 degrees to gain S-band communications, and the resulting attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 9 minutes after the CSM enters darkness. Seventeen minutes before the CSM enters sunlight, the inertial attitude hold is terminated, and the CSM is maneuvered to an attitude which allows dark side and solar corona photography. The vehicle attitude, with respect to the local horizontal orientation, is a pitch of minus 20 degrees and a roll of 180 degrees. This attitude is held locally fixed for 15 minutes. The CSM is then maneuvered to an attitude which allows orbital navigation photography. This vehicle attitude, with respect to the local horizontal orientation, is a pitch of minus 70 degrees and a roll of 180 degrees. The attitude is held locally fixed through the completion of the eighth revolution.

This attitude sequence allows S-band communications from the completion of the landmark sighting sequence on the pseudo landing site landmark to the maneuver to the dark side and solar corona photography attitude.

5.9 Ninth Revolution (Figure 14)

The sequence of significant events that occur during the ninth revolution is as follows:

1. Orbital navigation photography (convergent stereo photography)
2. Acquisition of MSFN line of sight
3. Enter darkness
4. IMU realignment
5. Loss of MSFN line of sight
6. Enter sunlight

At the start of the ninth revolution, the CSM is in the orbital navigation photography attitude. This attitude is held locally fixed until the CSM passes over the subsolar point. The CSM is then pitched 40 degrees and rolled 180 degrees, and the resulting attitude is held locally fixed while the convergent stereo photography continues. Approximately one minute after the CSM enters darkness, the local attitude hold is terminated, and the CSM is rolled 180 degrees and pitched minus 57.5 degrees. The resulting attitude is then held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment occurring approximately 15 minutes after the CSM enters darkness. At the loss of MSFN line of sight, the inertial attitude hold is terminated, and

the CSM is maneuvered to a lunar observation attitude. The vehicle attitude, with respect to the local horizontal orientation, is a pitch of minus 45 degrees and a roll of 180 degrees. This attitude is held locally fixed through the completion of the ninth revolution.

This attitude sequence allows S-band communications from 11 minutes prior to the termination of orbital navigation photography to the loss of MSFN line of sight.

5.10 Tenth Revolution (Figure 15)

The sequence of significant events that occur during the tenth revolution is as follows:

1. Acquisition of MSFN line of sight
2. Enter darkness
3. IMU realignment
4. Loss of MSFN line of sight
5. Enter sunlight
6. Transearth injection (TEI) burn

At the start of the tenth revolution, the CSM is in the locally fixed lunar observation attitude. Approximately 20 minutes before the CSM enters darkness, the local attitude hold is terminated, and the existing attitude is held inertially fixed. This inertially fixed attitude satisfies the attitude requirements for the IMU realignment beginning as the CSM enters darkness. Approximately 9 minutes before the CSM enters sunlight, the inertial attitude hold is terminated, and the vehicle is maneuvered to the TEI burn attitude. The burn attitude is then held inertially fixed through the burn. The TEI burn boosts the CSM from the 60-nautical mile circular lunar orbit into the transearth trajectory. The burn is performed with the CSM in a posigrade attitude, and the crew is heads down to afford visual reference with the lunar surface.

This attitude sequence allows S-band communications from acquisition of MSFN line of sight to loss of MSFN line of sight.

6. TRANSEARTH PHASE

Spacecraft look angles and IMU gimbal angles for the major events during the transearth phase of the mission are given in Table II(d).

6.1 Post-TEI Sequence of Events

Cutoff of the TEI burn occurs at 89:06:53 g. e. t. Following the burn termination, the CSM X-axis is positioned along the negative moon radius vector with the Z-axis in the direction of motion and in the plane of the trajectory. This orientation provides the crew with visual observation of the moon and is also acceptable for S-band/MSFN communications when earth line of sight is acquired.

Approximately one hour after TEI, the IMU will be realigned, and star/lunar landmark navigation sightings will be performed. The CSM will then be oriented for the first transearth PTC period.

6.2 Passive Thermal Control Tumble Mode

A type of PTC designated as the PTC tumble mode was simulated for the first transearth PTC period of approximately 5 hours. This mode has been included in the timeline to obtain thermal and stability characteristics of the spacecraft while in this attitude mode.

The initial PTC tumble mode orientation is as follows. The CSM X-axis is pointed towards the sun and the CSM Z-axis is 45 degrees below the trajectory plane pointing in the general direction of the earth. With this initial attitude a yaw rate of two revolutions per hour is then induced which turns the X-axis through 360 degrees with respect to the sun. The CSM attitude chosen for the tumble mode simulation in this timeline has been derived by considering S-band communications and gimbal lock avoidance requirements. The PTC tumble mode orientation with the appropriate earth-moon-sun geometry is shown in Figure 16.

6.3 Pre-Entry Sequence of Events

Prior to the time set for the final TE MCC, the IMU will be aligned to the entry REFSMMAT. Attitude maneuvers after this event thus will reflect the change in alignment of the IMU. Following the last MCC time, the crew performs an IMU realignment. This alignment is performed in the entry attitude which is a pitch maneuver of 156 degrees from the entry REFSMMAT alignment of 0, 0, 0 (roll, pitch, yaw) gimbal angles. This maneuver results in a heads-down retrograde attitude held inertially fixed until approximately 17 minutes prior to entry. At this time, the spacecraft orients to the CM/SM separation attitude with the X-axis in a

retrograde position 32 degrees below the local horizontal. The spacecraft is yawed positively through 45 degrees, and the crew is heads down. After separation, at entry minus 15 minutes, the CM returns to the entry attitude. The CM/SM separation and spacecraft entry attitude are shown in Figures 17a and 17b, respectively.

Table I. C-prime Lunar Orbit Mission Event Sequence

Mission Time (hr:min:sec)	Event
	Earth Orbit
00:11:20	Earth orbit insertion, inertial attitude hold
00:11:35	Orient S-IVB/CSM to + X-axis forward, heads down, Z-axis inplane, initiate local attitude hold
02:50:31	Initiate TLI burn
	Translunar
02:55:43	TLI cutoff, inertial attitude hold
02:56:03	Orient S-IVB/CSM to + X-axis forward, heads down, Z-axis inplane, initiate local attitude hold
03:10:43	Orient to S-IVB/CSM separation attitude, inertial attitude hold
03:20:43	S-IVB/CSM separation, inertial attitude hold
03:21:43	Execute 180-deg pitch at 5 deg/sec
03:22:23	Execute negative 60-deg roll, begin station keeping
03:35:43	Orient to evasive maneuver attitude
05:07:43	Orient to optical monitoring of S-IVB attitude
06:00:00	Orient to navigation sighting attitude
06:10:00	Perform star/earth horizon navigation sightings
07:00:00	Complete navigation sightings and initiate 45-deg roll to IMU alignment attitude
07:10:00	Perform IMU fine alignment
07:30:00	Complete IMU fine alignment and roll 180 deg
08:00:00	Orient to IMU alignment attitude
08:10:00	Perform IMU fine alignment
08:30:00	Complete IMU alignment
09:00:00	Initiate spacecraft midcourse correction
09:10:00	Orient to navigation sighting attitude
09:20:00	Perform star/earth landmark navigation sightings
09:50:00	Complete navigation sightings and orient for PTC
10:05:00	Establish pitch-yaw hold; initiate 0. 2-deg/sec roll rate
15:50:00	Complete PTC and orient to navigation sighting attitude

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Translunar (Continued)
16:00:00	Perform star/earth horizon navigation sightings
16:50:00	Complete navigation sighting and orient for PTC
17:05:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
26:20:00	Complete PTC and orient to navigation sighting attitude
26:30:00	Perform star/earth horizon navigation sightings
27:00:00	Complete navigation sightings and orient to IMU alignment attitude
27:10:00	Perform IMU alignment
27:30:00	Complete IMU alignment
28:00:00	Initiate spacecraft midcourse correction
28:10:00	Orient to navigation sighting attitude
28:20:00	Perform star/earth horizon navigation sightings
29:00:00	Complete navigation sighting and orient for PTC
29:15:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
34:10:00	Complete PTC and orient to navigation sighting attitude
34:20:00	Perform star/earth horizon navigation sightings
34:50:00	Complete navigation sighting and orient for PTC
35:05:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
45:00:00	Complete PTC and orient to navigation sighting attitude
45:10:00	Perform star/lunar horizon navigation sightings
46:00:00	Complete navigation sighting and orient to IMU alignment attitude
46:10:00	Perform IMU alignment
46:30:00	Complete IMU alignment
47:00:00	Initiate spacecraft midcourse correction
47:10:00	Orient to navigation sighting attitude
47:20:00	Perform star/earth horizon navigation sightings
47:50:00	Complete navigation sighting and orient for PTC
48:05:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
56:50:00	Complete PTC and orient to navigation sighting attitude
57:00:00	Perform star/lunar horizon navigation sightings

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Translunar (Continued)
57:50:00	Complete navigation sightings and orient for PTC
58:05:00	Establish pitch-yaw hold, initiate 0.2-deg/sec roll rate
60:05:00	Complete PTC and orient to IMU alignment attitude
60:15:00	Perform IMU alignment
60:30:00	Complete IMU alignment
61:00:00	Initiate spacecraft midcourse correction
61:15:00	Orient for PTC
61:30:00	Establish pitch-yaw hold, initiate 0.2-deg/sec roll rate
65:50:00	Complete PTC and orient to IMU alignment attitude
66:00:00	Perform IMU alignment
66:20:00	Complete IMU alignment and orient for PTC
66:35:00	Establish pitch-yaw hold, initiate 0.2-deg/sec roll rate
68:05:00	Complete PTC and orient to IMU alignment attitude
68:15:00	Perform IMU alignment
68:35:00	Complete IMU alignment
69:07:29	Initiate LOI-1 burn
	Lunar Orbit
69:11:35	LOI-1 cutoff, inertial attitude hold
69:29:00	Roll 180 deg for communications, inertial attitude hold
69:30:20	Acquire Honeysuckle Creek signal
70:14:12	Enter lunar umbra, begin IMU realignment
70:36:35	Acquire Madrid signal
70:54:58	Lose Madrid signal
70:55:13	Lose Honeysuckle Creek signal, maneuver to lunar observation and photography attitude, local attitude hold
71:00:26	Enter sunlight
71:38:25	Acquire Madrid signal
71:38:35	Acquire Honeysuckle Creek signal
72:08:30	Lose Honeysuckle Creek signal

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Lunar Orbit (Continued)
72:15:00	Terminate local attitude hold and begin inertial attitude hold
72:22:47	Enter lunar umbra
72:27:00	Begin IMU realignment
72:55:00	Maneuver to circularization burn attitude except rolled 180-deg, inertial attitude hold
73:03:18	Lose Madrid signal
73:05:00	Roll 180 deg to circularization burn attitude, inertial attitude hold
73:09:01	Enter sunlight
73:30:53	Initiate circularization burn
73:31:03	Circularization burn cutoff, inertial attitude hold
73:40:00	Maneuver to landmark training photography attitude, local attitude hold
73:47:48	Acquire Madrid signal
74:14:16	Start manual pitch rate for landmark training photography
74:16:33	Terminate pitch rate, pitch up for IMU realignment, inertial attitude hold
74:22:53	Enter lunar umbra
74:30:00	Begin IMU realignment
74:55:00	Maneuver to orbital navigation photography attitude, local attitude hold
74:59:49	Lose Madrid signal
75:09:00	Enter sunlight
75:44:00	Roll 180 deg, continue orbital navigation photography, local attitude hold
75:46:11	Acquire Madrid signal
76:00:00	Maneuver to landmark evaluation attitude, local attitude hold
76:10:20	Start -0. 3 deg/sec pitch rate for landmark evaluation
76:14:49	Terminate pitch rate, roll 180 deg, inertial attitude hold
76:21:29	Enter lunar umbra
76:30:00	Begin IMU realignment
76:58:10	Lose Madrid signal

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Lunar Orbit (Continued)
77:00:00	Maneuver to landmark sighting attitude, local attitude hold
77:07:35	Enter sunlight
77:30:19	Start -0.3 deg/sec pitch rate for second control point landmark sighting
77:34:48	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
77:44:32	Acquire Madrid signal
78:08:09	Acquire Goldstone signal
78:08:36	Start -0.3 deg/sec pitch rate for pseudo landing site sighting
78:13:05	Terminate pitch rate, roll 180 deg, inertial attitude hold
78:20:05	Enter lunar umbra
78:35:00	Begin IMU realignment
78:56:11	Lose Goldstone signal
78:56:32	Lose Madrid signal
79:06:00	Maneuver to landmark sighting attitude, local attitude hold
79:06:12	Enter sunlight
79:28:3	Start -0.3 deg/sec pitch rate for second control point landmark sighting
79:33:05	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
79:42:30	Acquire Goldstone signal
79:42:51	Acquire Madrid signal
80:06:52	Start -0.3 deg/sec pitch rate for pseudo landing site sighting
80:11:21	Terminate pitch rate, roll 180 deg, inertial attitude hold
80:18:41	Enter lunar umbra
80:32:00	Begin IMU realignment
80:54:28	Lose Goldstone signal
80:54:50	Lose Madrid signal

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Lunar Orbit (Continued)
81:00:00	Maneuver to landmark sighting attitude, local attitude hold
81:04:48	Enter sunlight
81:12:25	Start -0.3 deg/sec pitch rate for first control point landmark sighting
81:16:54	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
81:26:53	Start -0.3 deg/sec pitch rate for second control point landmark sighting
81:31:22	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
81:40:51	Acquire Goldstone signal
81:44:48	Start -0.3 deg/sec pitch rate for third control point landmark sighting
81:49:17	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
82:05:08	Start -0.3 deg/sec pitch rate for pseudo landing site sighting
82:09:37	Terminate pitch rate, roll 180 deg, inertial attitude hold
82:17:17	Enter lunar umbra
82:30:00	Begin IMU realignment
82:52:49	Lose Goldstone signal
83:00:00	Maneuver to landmark sighting attitude, local attitude hold
83:03:24	Enter sunlight
83:10:42	Start -0.3 deg/sec pitch rate for first control point landmark sighting
83:15:11	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
83:25:09	Start -0.3 deg/sec pitch rate for second control point landmark sighting
83:29:38	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
83:39:13	Acquire Goldstone signal
83:43:05	Start -0.3 deg/sec pitch rate for third control point landmark sighting

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Lunar Orbit (Continued)
83:45:31	Acquire Honeysuckle Creek signal
83:47:34	Terminate pitch rate, maneuver to landmark sighting attitude, local attitude hold
84:03:24	Start -0. 3 deg/sec pitch rate for pseudo landing site sighting
84:07:53	Terminate pitch rate, roll 180 deg, inertial attitude hold
84:15:54	Enter lunar umbra
84:25:00	Begin IMU realignment
84:45:00	Maneuver to darkside and solar corona photography attitude, local attitude hold
84:50:47	Lose Honeysuckle Creek signal
84:51:14	Lose Goldstone signal
85:00:00	Maneuver to orbital navigation photography attitude, local attitude hold
85:02:00	Enter sunlight
85:37:00	Pitch 40 deg, roll 180 deg and continue orbital navigation photography, local attitude hold
85:37:06	Acquire Honeysuckle Creek signal
85:37:35	Acquire Goldstone signal
86:14:30	Enter lunar umbra
86:16:00	Roll 180 deg, pitch up for IMU realignment, inertial attitude hold
86:30:00	Begin IMU realignment
86:49:05	Lose Honeysuckle Creek signal
86:49:35	Lose Goldstone signal
86:50:00	Maneuver to lunar observation attitude, local attitude hold
87:00:37	Enter sunlight
87:35:27	Acquire Honeysuckle Creek signal
87:35:54	Acquire Goldstone signal
87:53:00	Terminate local attitude hold, start inertial attitude hold
88:13:05	Enter lunar umbra, begin IMU realignment
88:47:25	Lose Honeysuckle Creek signal

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Lunar Orbit (Continued)
88:47:53	Lose Goldstone signal
88:50:00	Maneuver to TEI burn attitude, inertial attitude hold
88:59:12	Enter sunlight
89:04:02	Initiate TEI burn
	Transearth
89:06:53	TEI cutoff, orient to vertical (+ X down, + Z, forward), inertial attitude hold
90:00:00	Orient to IMU alignment attitude
90:10:00	Perform IMU alignment
90:30:00	Complete IMU alignment and orient to navigation sighting attitude
90:40:00	Perform star/lunar landmark navigation sightings
92:00:00	Complete navigation sighting and orient for PTC tumble mode
92:15:00	Establish pitch-roll hold, initiate 0.2-deg/sec yaw rate
97:10:00	Complete PTC and orient to navigation sighting attitude
97:20:00	Perform star/lunar horizon navigation sightings
98:00:00	Complete navigation sighting and orient to IMU alignment attitude
98:10:00	Perform IMU alignment
98:30:00	Complete IMU alignment
99:00:00	Initiate spacecraft midcourse correction
99:10:00	Orient for navigation sighting attitude
99:20:00	Perform star/earth horizon navigation sightings
99:50:00	Complete navigation sighting and orient for PTC
100:05:00	Establish pitch-yaw hold, initiate 0.2-deg/sec roll rate
106:10:00	Complete PTC and orient to navigation sighting attitude
106:20:00	Perform star/lunar horizon navigation sightings
106:50:00	Complete navigation sighting and orient for PTC
107:05:00	Establish pitch-yaw hold, initiate 0.2-deg/sec roll rate

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Transearth (Continued)
116:00:00	Complete PTC and orient for navigation sightings
116:10:00	Perform star/lunar horizon navigation sightings
117:00:00	Complete navigation sighting and orient to IMU alignment attitude
117:10:00	Perform IMU alignment
117:30:00	Complete IMU alignment
118:00:00	Initiate spacecraft midcourse correction
118:10:00	Orient to navigation sighting attitude
118:20:00	Perform star/earth horizon navigation sightings
118:50:00	Complete navigation sighting and orient for PTC
119:05:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
128:50:00	Complete PTC and orient for navigation sightings
129:00:00	Perform star/earth horizon navigation sightings
129:30:00	Complete earth navigation sighting and orient for lunar navigation sightings
129:40:00	Perform star/lunar horizon navigation sightings
130:10:00	Complete navigation sighting and orient for PTC
130:25:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
140:00:00	Complete PTC and orient to navigation sighting attitude
140:10:00	Perform star/lunar horizon navigation sightings
141:00:00	Complete navigation sighting and orient to IMU alignment attitude
141:10:00	Perform IMU alignment
141:30:00	Complete IMU alignment
142:00:00	Initiate spacecraft midcourse correction
142:10:00	Orient to navigation sighting attitude
142:20:00	Perform star/earth horizon navigation sightings
142:50:00	Complete navigation sighting and orient for PTC
143:05:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
148:50:00	Complete PTC and orient to navigation sighting attitude
149:00:00	Perform star/earth horizon navigation sightings

Table I. C-prime Lunar Orbit Mission Event Sequence (Continued)

Mission Time (hr:min:sec)	Event
	Transearth (Continued)
149:50:00	Complete navigation sighting and orient for PTC
150:05:00	Establish pitch-yaw hold, initiate 0. 2-deg/sec roll rate
155:50:00	Complete PTC and orient to navigation sighting attitude
156:00:00	Perform star/earth horizon navigation sightings
156:30:00	Reorient and perform star/lunar landmark navigation sightings
157:00:00	Complete navigation sighting and orient for PTC
157:15:00	Establish pitch-yaw hold, initiate 0. 2 deg/sec roll rate
167:30:00	Complete PTC and orient to IMU orientation determination
168:00:00	Complete IMU orientation determination and orient to IMU alignment attitude
168:10:00	Perform IMU alignment
168:30:00	Complete IMU alignment
169:05:00	Initiate spacecraft midcourse correction
170:00:00	Perform IMU alignment
170:20:00	Complete IMU alignment
170:48:32	Orient to separation attitude
170:50:32	CM/SM separation
171:05:32	Entry

Table II. Spacecraft Attitude Data
(a) Earth Orbit

Mission Time (hr:min:sec)	Event	Geographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Comments
		Attitude* (n mi)	Latitude* (deg)	Longitude* (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	
00:11:20	Earth orbit insertion	103.3	32.5	-54.3	0.0	0.0	180.0	-115.3	0.6	-179.2	Inertial hold
00:11:35	Begin local attitude hold	103.3	32.5	-52.8	0.0	0.0	180.0	-115.3	0.6	-179.2	
02:50:31	Initiate TLI burn	99.5	9.5	-165.9	0.0	0.0	180.0	-45.8	1.1	179.3	Terminate local attitude hold

*Altitude is measured with respect to the Fischer reference ellipsoid; latitude and longitude are measured positive north of the equator and east from the Greenwich meridian, respectively.

Table II. Spacecraft Attitude Data
(b) Translunar

Mission Time (hr:min:sec)	Event	Geocentric Inertial Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		Comments
		Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
2:55:43	TLI cutoff	-63.7	-66.4	5.8	-70.5	3.9	-179.8	90.0	0.0	50.3	-44.0	45.7	-81.8	Inertial hold at cutoff not simulated
2:56:03	Begin local attitude hold	-63.7	-66.4	5.8	-70.5	3.9	-179.8	90.0	0.0	50.3	-44.0	45.7	-81.8	Inertial hold
3:10:43	S-IVB/CSM orient to separation attitude	-141.0	-36.9	-60.2	-18.8	2.6	177.1	160.0	180.0	93.0	-32.9	69.3	-49.2	Begin inertial hold
3:20:43	S-IVB/CSM separation	-141.0	-36.9	-60.2	-18.8	2.6	177.1	140.5	180.0	93.3	-33.3	69.3	-49.2	Separation distance ≈ 50 ft
3:21:43	Pitch 180 deg	39.0	36.9	60.2	161.2	-2.6	-177.1	39.5	0.0	86.7	-146.7	110.7	-130.8	5 deg/sec maneuver rate
3:22:23	Roll negative 60 deg	39.0	36.9	0.2	161.2	-2.6	122.9	40.4	60.0	86.7	-86.7	110.7	-70.8	5 deg/sec maneuver rate
3:35:43	Evasive maneuver	120.6	66.2	170.3	107.7	-3.9	-0.3	0.0	-0.8	129.1	45.5	134.5	83.4	Begin inertial hold
5:07:43	Optically monitor S-IVB	-169.4	47.9	-104.8	69.0	-14.0	139.8	14.9	-94.4	155.6	-58.2	136.8	-20.0	Begin inertial hold
6:00:00	Orient for navigation sighting	-169.4	47.9	-104.8	69.0	-14.0	139.8	11.9	-73.3	154.8	-57.8	136.8	-20.0	Continue inertial hold
6:10:00	Perform SEH navigation sightings	86.4	58.9	-156.3	124.0	1.6	2.9	51.3	-177.7	112.2	41.0	125.5	68.1	Begin inertial hold
7:00:00	Complete navigation sightings	86.4	58.9	-156.3	124.0	1.6	2.9	54.6	-178.2	112.0	41.7	125.5	68.0	Begin roll 45 deg for IMU attitude
7:10:00	Perform IMU alignment	86.4	58.9	-111.3	124.0	1.6	47.9	55.2	136.7	112.0	-3.2	125.5	23.0	Continue inertial hold
7:30:00	Complete IMU alignment	86.4	58.9	-111.3	124.0	1.6	47.9	56.2	136.6	112.0	-3.0	125.5	23.0	Begin roll 180 deg
8:00:00	Orient for IMU alignment	86.4	58.9	68.7	124.0	1.6	-132.1	57.6	-43.6	111.9	177.4	125.5	-157.0	0.5 deg/sec maneuver rate
8:10:00	Perform IMU alignment	86.4	58.9	68.7	124.0	1.6	-132.1	58.0	-43.7	111.9	177.5	125.5	-157.0	Continue inertial hold
8:30:00	Complete IMU alignment	86.4	58.9	68.7	124.0	1.6	-132.1	58.8	-43.8	111.8	177.8	125.5	-157.0	Continue inertial hold
9:00:00	Initiate midcourse correction	86.4	58.9	68.7	124.0	1.6	-132.1	59.9	-43.9	111.8	178.1	125.5	-157.1	Continue inertial hold
9:10:00	Orient for navigation sightings	86.4	58.9	68.7	124.0	1.6	-132.1	60.2	-43.9	111.8	178.2	125.5	-157.1	0.5 deg/sec maneuver rate
9:20:00	Perform SEL navigation sightings	179.7	-19.9	-90.8	12.2	26.5	157.8	57.5	180.0	96.4	-30.6	71.8	-24.0	Begin inertial hold
9:50:00	Complete navigation sightings; orient for PTC	179.7	-19.9	-90.8	12.2	26.5	157.8	56.7	179.5	96.1	-30.8	71.8	-23.9	0.5 deg/sec maneuver rate
10:05:00	Start PTC	-106.5	-22.6	-40.1	-29.1	-28.8	177.1	90.0	180.0	105.7	-36.4	90.0	-56.3	Roll at 0.2 deg/sec
15:50:00	Complete PTC; orient for navigation sightings	-106.5	-22.6	139.9	-29.1	-28.8	-2.9	84.8	3.3	105.9	140.8	90.0	123.9	0.5 deg/sec maneuver rate
16:00:00	Perform SEH navigation sightings	111.8	44.7	-164.7	110.7	18.0	16.9	57.5	177.8	105.8	41.8	112.6	65.1	Begin inertial hold
16:50:00	Complete navigation sightings; orient for PTC	111.8	44.7	-164.7	110.7	18.0	16.9	58.0	177.5	105.7	42.1	112.6	65.1	Continue inertial hold
17:05:00	Start PTC	-99.1	-23.2	-33.3	-36.1	-32.1	177.5	90.0	180.0	103.9	-41.9	90.0	-60.0	Roll at 0.2 deg/sec
26:20:00	Complete PTC; orient for navigation sightings	-99.1	-23.2	146.7	-36.1	-32.1	-2.5	86.4	2.5	104.2	135.2	90.0	120.4	0.5 deg/sec maneuver rate
26:30:00	Perform SEH navigation sightings	118.0	43.5	-172.9	105.9	18.8	14.5	58.0	-179.7	105.9	50.2	112.4	70.5	Begin inertial hold
27:00:00	Complete navigation sightings; begin reorientation	118.0	43.5	-172.9	105.9	18.8	14.5	58.1	-179.8	105.9	50.3	112.4	70.5	0.5 deg/sec maneuver rate
27:10:00	Perform IMU alignment	118.0	43.5	-172.9	105.9	18.8	14.5	58.2	-179.8	105.8	50.3	112.4	70.5	Continue inertial hold
27:30:00	Complete IMU alignment	118.0	43.5	-172.9	105.9	18.8	14.5	58.3	-179.9	105.8	50.4	112.4	70.5	Continue inertial hold
28:00:00	Initiate midcourse correction	118.0	43.5	-172.9	105.9	18.8	14.5	58.4	180.0	105.8	50.5	112.5	70.5	Continue inertial hold
28:10:00	Orient for navigation sightings	118.0	43.5	-172.9	105.9	18.8	14.5	58.4	180.0	105.7	50.6	112.5	70.5	0.5 deg/sec maneuver rate
28:20:00	Perform SEH navigation sightings	120.4	44.0	-174.2	104.1	18.1	15.5	56.7	179.3	107.1	50.5	113.3	70.7	Begin inertial hold
29:00:00	Complete navigation sightings; orient for PTC	120.4	44.0	-174.2	104.1	18.1	15.5	56.9	179.2	107.0	50.7	113.3	70.7	0.5 deg/sec maneuver rate
29:15:00	Start PTC	-93.8	-23.5	-28.0	-41.3	-34.2	177.8	90.0	180.0	102.9	-47.5	90.0	-62.6	Roll at 0.2 deg/sec
34:10:00	Complete PTC; orient for navigation sightings	-93.8	-23.5	-88.0	-41.3	-34.2	117.8	88.9	-119.2	103.1	11.4	90.0	-2.4	0.5 deg/sec maneuver rate
34:20:00	Perform SEH navigation sightings	-132.5	-19.8	-48.8	-9.0	-13.3	-174.6	58.0	-179.1	107.2	-52.7	88.7	-56.0	Begin inertial hold
34:50:00	Complete navigation sightings; orient for PTC	-132.5	-19.8	-48.8	-9.0	-13.3	-174.6	57.9	-179.0	107.2	-52.8	88.7	-56.0	0.5 deg/sec maneuver rate
35:05:00	Start PTC	-92.3	-23.5	-26.5	-42.8	-34.8	177.8	90.0	180.0	102.7	-49.4	90.0	-63.3	Roll at 0.2 deg/sec

Table II. Spacecraft Attitude Data
(b) Translunar (Continued)

Mission Time (hr:min:sec)	Event	Geocentric Inertial Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		Comments
		Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
45:00:00	Complete PTC; orient for navigation sightings	-92.3	-23.5	-86.5	-42.8	-34.8	117.8	88.4	-118.8	102.9	8.7	90.0	-2.9	0.5 deg/sec maneuver rate
45:10:00	Perform SLH navigation sightings	6.9	-19.1	130.1	-135.1	-2.4	-109.9	175.6	0.0	57.5	180.0	68.3	164.8	Begin inertial hold
46:00:00	Complete navigation sightings	6.9	-19.1	130.1	-135.1	-2.4	-109.9	175.4	0.1	57.3	179.9	68.3	164.8	Continue inertial hold
46:10:00	Perform IMU alignment	6.9	-19.1	130.1	-135.1	-2.4	-109.9	175.4	0.0	57.3	180.0	68.3	164.8	Continue inertial hold
46:30:00	Complete IMU alignment	6.9	-19.1	130.1	-135.1	-2.4	-109.9	175.3	0.0	57.2	180.0	68.3	164.8	Continue inertial hold
47:00:00	Initiate midcourse correction	6.9	-19.1	130.1	-135.1	-2.4	-109.9	175.2	0.1	57.0	179.9	68.4	164.8	Continue inertial hold
47:10:00	Orient for navigation sightings	6.9	-19.1	130.1	-135.1	-2.4	-109.9	175.2	0.1	57.0	179.9	68.4	164.8	0.5 deg/sec maneuver rate
47:20:00	Perform SEH navigation sightings	165.4	-30.3	-117.4	4.6	41.9	141.7	57.5	180.0	70.4	-13.3	58.3	-0.1	Begin inertial hold
47:50:00	Complete navigation sightings; orient for PTC	165.4	-30.3	-117.4	4.6	41.9	141.7	57.5	179.9	70.3	-13.3	58.3	-0.1	0.5 deg/sec maneuver rate
48:05:00	Start PTC	-89.9	-23.4	-24.1	-45.3	-35.7	177.9	90.0	180.0	102.4	-52.8	90.0	-64.2	Roll at 0.2 deg/sec
56:50:00	Complete PTC; orient for navigation sightings	-89.9	-23.4	155.9	-45.3	-35.7	-2.1	89.0	0.7	102.5	125.2	90.0	116.2	0.5 deg/sec maneuver rate
57:00:00	Perform SLH navigation sightings	10.0	-19.9	129.7	-135.8	0.6	-111.3	178.7	0.3	57.5	180.0	65.8	165.3	Begin inertial hold
57:50:00	Complete navigation sightings; orient for PTC	10.0	-19.9	129.7	-135.8	0.6	-111.3	178.5	0.0	57.3	179.9	65.8	165.3	0.5 deg/sec maneuver rate
58:05:00	Start PTC	-88.5	-23.4	-22.8	-46.8	-36.2	177.8	90.0	180.0	102.3	-55.7	90.0	-64.6	Roll at 0.2 deg/sec
60:05:00	Complete PTC; orient for IMU alignment	-88.5	-23.4	-22.8	-46.8	-36.2	177.8	89.8	-179.9	102.3	-56.6	90.0	-64.5	0.5 deg/sec maneuver rate
60:15:00	Perform IMU alignment	10.9	-20.8	25.1	107.2	6.8	-98.0	179.7	-153.1	57.6	-75.4	64.5	-90.0	Pitch 90 deg, change to LOI-2 REFSMMAT, inertial hold
60:30:00	Complete IMU alignment	10.9	-20.8	25.1	107.2	6.8	-98.0	179.7	-153.3	57.7	-75.4	64.5	-90.0	Continue inertial hold
61:00:00	Initiate midcourse correction	10.9	-20.8	25.1	107.2	6.8	-98.0	179.7	-153.8	58.0	-75.4	64.4	-90.0	Continue inertial hold
61:15:00	Orient for PTC	10.9	-20.8	25.1	107.2	6.8	-98.0	179.6	-154.1	58.2	-75.4	64.4	-90.0	Continue inertial hold
61:30:00	Start PTC	46.7	19.2	-76.0	122.1	-44.7	165.7	127.2	122.9	76.4	3.4	90.0	0.2	Roll at 0.2 deg/sec
65:50:00	Complete PTC	46.7	19.2	164.0	122.1	-44.7	45.6	127.7	-117.0	80.5	127.9	90.0	120.0	Terminate roll, inertial hold
66:00:00	Perform IMU alignment	46.7	19.2	164.0	122.1	-44.7	45.6	127.7	-117.0	80.9	128.2	90.0	120.0	Continue inertial hold
66:20:00	Complete IMU alignment	46.7	19.2	164.0	122.1	-44.7	45.6	127.7	-117.0	81.7	129.1	90.0	120.0	Continue inertial hold
66:35:00	Start PTC	46.7	19.2	-76.0	122.1	-44.7	165.7	127.7	123.1	82.4	9.9	90.0	0.0	Roll at 0.2 deg/sec
68:05:00	Complete PTC; orient for IMU alignment	46.7	19.2	-76.0	122.1	-44.7	165.7	127.9	123.3	92.4	19.9	90.0	0.0	0.5 deg/sec maneuver rate
68:15:00	Perform IMU alignment	-52.3	44.3	166.4	-165.0	6.9	14.6	92.8	-20.5	171.0	-175.2	147.8	133.5	Performed in LOI burn attitude, inertial hold
68:35:00	Complete IMU alignment	-52.3	44.3	166.4	-165.0	6.9	14.6	92.7	-20.5	173.5	-33.4	147.8	133.5	Continue inertial hold
69:07:29	Initiate LOI-1 burn	-52.3	44.3	166.4	-165.0	6.9	14.6	No line of sight		97.9	-15.2	147.8	133.5	Continue inertial hold

Table II. Spacecraft Attitude Data
(c) Lunar Orbit

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles To Earth		Look Angles To Sun		Look Angles To Landmark		Comment
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
69:11:35	LOI-1 cutoff	59.4	-10.1	178.4	-171.6	6.9	0.5	-165.0	6.9	0.5	No line of sight		147.8	147.7			Begin inertial hold
69:29:00	Roll 180 deg for communication	75.1	-11.7	123.6	-118.0	6.9	-179.5	-165.0	6.9	-179.5	No line of sight		147.8	-32.3			Begin inertial hold
69:30:20	Acquire MSFN line of sight	77.7	-11.4	119.5	-114.0	6.9	-179.5	-165.0	6.9	-179.5	92.3	174.2	147.8	-32.3			Continue inertial hold
70:14:12	Enter lunar umbra	167.3	9.6	0.9	5.3	6.9	-179.5	-165.0	6.9	-179.5	93.0	174.2	No line of sight				Continue inertial hold
70:14:12	Begin IMU realignment	167.3	9.6	0.9	5.3	6.9	-179.5	-165.0	6.9	-179.5	93.0	174.2	No line of sight				Continue inertial hold
70:55:13	Lose MSFN line of sight	103.0	4.2	-108.8	113.3	6.9	-179.5	-165.0	6.9	-179.5	No line of sight		No line of sight				Continue inertial hold
71:55:13	Maneuver to lunar observation and photography attitude	103.0	4.2	-108.8	-45.0	0.0	180.0	36.8	0.0	180.0	No line of sight		No line of sight				Begin local hold
71:00:26	Enter sunlight	89.9	1.2	-123.0	-45.0	0.0	180.0	21.9	0.0	180.0	No line of sight		22.6	-154.7			Continue local hold
71:38:25	Acquire MSFN line of sight	77.6	11.2	118.4	-45.0	0.0	180.0	-95.9	0.0	180.0	24.4	166.4	137.5	-164.8			Continue local hold
72:15:00	Terminate local hold; begin inertial hold	160.4	6.5	19.7	-45.0	0.0	180.0	164.6	0.0	180.0	123.7	173.3	121.5	-11.9			Begin inertial hold
72:22:47	Enter lunar umbra	167.2	9.6	0.1	-25.5	0.0	180.0	164.6	0.0	180.0	123.9	173.3	No line of sight				Continue inertial hold
72:27:00	Begin IMU realignment	168.2	10.9	-11.0	-14.5	0.0	180.0	164.6	0.0	180.0	124.0	173.3	No line of sight				Continue inertial hold
72:55:00	Maneuver to circularization burn attitude except rolled 180 deg	126.4	8.7	-85.1	73.6	0.0	180.0	180.0	0.0	180.0	109.1	174.2	No line of sight				Begin inertial hold
73:03:18	Lose MSFN line of sight	104.5	4.5	-108.2	96.8	0.0	180.0	180.0	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
73:05:00	Roll 180 deg to circularization burn attitude	100.1	3.5	-112.9	101.6	0.0	0.0	180.0	0.0	0.0	No line of sight		No line of sight				Begin inertial hold
73:09:01	Enter sunlight	89.9	1.1	-124.3	113.1	0.0	0.0	180.0	0.0	0.0	No line of sight		136.5	165.2			Continue inertial hold
73:30:53	Circularization burn initiation	59.0	-10.8	169.6	179.7	0.0	0.0	180.0	0.0	0.0	No line of sight		136.4	165.2			Continue inertial hold
73:31:03	Circularization burn cutoff	59.0	-10.9	169.1	-179.8	0.0	0.0	180.0	0.0	0.0	No line of sight		136.4	165.2			Continue inertial hold
73:40:00	Maneuver to landmark training photography attitude	59.0	-12.3	141.3	-52.5	0.0	180.0	-79.9	0.0	180.0	No line of sight		121.9	-168.0			Begin local hold
73:47:48	Acquire MSFN line of sight	58.8	-11.3	117.1	-52.5	0.0	180.0	-103.6	0.0	180.0	33.0	169.9	144.8	-162.1			Continue local hold
74:14:16	Start manual pitch rate for pseudo landing site landmark training photography	58.0	2.8	37.3	-52.5	0.0	180.0	176.1	0.0	180.0	113.2	174.0	132.7	-13.9	5.9	8.9	Begin manual pitch rate
74:16:33	Terminate manual pitch; pitch -70 deg	58.0	4.2	30.5	-72.4	0.0	180.0	149.3	0.0	180.0	139.9	171.5	106.4	-10.6	69.3	6.6	Begin inertial hold
74:22:53	Enter lunar umbra	57.9	7.4	11.4	-53.2	0.0	180.0	149.3	0.0	180.0	140.1	171.4	No line of sight				Continue inertial hold
74:30:00	Begin IMU realignment	57.8	10.8	-10.9	-31.1	0.0	180.0	149.3	0.0	180.0	140.2	171.4	No line of sight				Continue inertial hold
74:55:00	Maneuver to orbital navigation photography attitude	58.3	8.4	-87.7	-90.0	0.0	180.0	14.9	0.0	180.0	84.6	5.5	No line of sight				Begin local hold
74:59:49	Lose MSFN line of sight	58.5	5.8	-102.3	-90.0	0.0	180.0	0.3	0.0	180.0	No line of sight		No line of sight				Continue local hold
75:09:00	Enter sunlight	58.8	0.2	-129.7	-90.0	0.0	180.0	-27.6	0.0	180.0	No line of sight		70.6	169.2			Continue local hold
75:44:00	Roll 180 deg; continue orbital navigation photography	58.9	-11.9	123.5	-90.0	0.0	0.0	-133.7	0.0	0.0	No line of sight		169.2	70.5			Begin local hold
75:46:11	Acquire MSFN line of sight	58.8	-11.4	116.4	-90.0	0.0	0.0	-140.3	0.0	0.0	70.6	-5.8	169.3	105.7			Continue local hold
76:00:00	Maneuver to landmark evaluation attitude	58.3	-5.4	74.7	5.0	0.0	0.0	-87.2	0.0	0.0	18.4	-17.5	129.2	13.1			Begin local hold
76:10:20	Start pitch rate for landmark evaluation of pseudo landing site	58.1	1.1	43.8	5.0	0.0	0.0	-118.6	0.0	0.0	49.4	-7.2	158.8	29.2	30.7	-174.7	-0.3 deg/sec pitch rate
76:14:49	Terminate pitch rate; roll 180 deg	57.9	4.0	30.5	-62.1	0.0	180.0	160.7	0.0	180.0	129.7	172.9	117.5	-11.5	79.3	4.4	Begin inertial hold
76:21:29	Enter lunar umbra	57.9	7.7	10.4	-41.9	0.0	180.0	160.7	0.0	180.0	129.9	172.9	No line of sight				Continue inertial hold
76:30:00	Begin IMU realignment	57.8	11.2	-15.7	-16.0	0.0	180.0	160.7	0.0	180.0	130.1	172.9	No line of sight				Continue inertial hold

Table II. Spacecraft Attitude Data
(c) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles To Earth		Look Angles To Sun		Look Angles To Landmark		Comment
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
76:58:10	Lose MSFN line of sight	58.5	6.0	-102.5	69.0	0.0	180.0	160.7	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
77:00:00	Maneuver to landmark sighting attitude	58.5	4.9	-108.0	5.0	0.0	0.0	90.6	0.0	0.0	No line of sight		No line of sight				Begin local hold
77:07:35	Enter sunlight	58.8	0.2	-130.7	5.0	0.0	0.0	67.6	0.0	0.0	No line of sight		5.7	4.2			Continue local hold
77:30:19	Start pitch rate for 2nd control point landmark sighting	59.1	-11.4	160.7	5.0	0.0	0.0	-1.4	0.0	0.0	No line of sight		45.0	14.4	30.7	-174.5	-0.3 deg/sec pitch rate
77:34:48	Terminate pitch rate; maneuver to landmark sighting attitude	59.0	-12.2	146.8	5.0	0.0	0.0	-15.0	0.0	0.0	No line of sight		58.3	12.0	145.3	-175.2	Begin local hold
77:44:32	Acquire MSFN line of sight	58.8	-11.5	116.0	5.0	0.0	0.0	-44.5	0.0	0.0	24.7	-167.0	87.4	10.2			Continue local hold
78:08:36	Start pitch rate for pseudo landing site landmark sighting	58.1	0.9	43.8	5.0	0.0	0.0	-117.5	0.0	0.0	49.4	-7.1	157.9	28.0	30.6	-177.1	-0.3 deg/sec pitch rate
78:13:05	Terminate pitch rate; roll 180 deg	58.0	3.8	30.5	-62.1	0.0	180.0	161.8	0.0	180.0	129.8	173.0	118.5	-11.6	79.0	2.4	Begin inertial hold
78:20:05	Enter lunar umbra	57.9	7.7	9.4	-34.7	0.0	180.0	161.8	0.0	180.0	129.9	173.0	No line of sight				Continue inertial hold
78:35:00	Begin IMU realignment	57.9	12.3	-36.5	4.5	0.0	180.0	161.8	0.0	180.0	130.3	173.0	No line of sight				Continue inertial hold
78:56:32	Lose MSFN line of sight	58.5	6.4	-103.0	68.5	0.0	180.0	161.8	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
79:06:00	Maneuver to landmark sighting attitude	58.7	0.3	-131.1	5.0	0.0	0.0	68.2	0.0	0.0	No line of sight		No line of sight				Begin local hold
79:06:12	Enter sunlight	58.7	0.2	-131.7	5.0	0.0	0.0	67.6	0.0	0.0	No line of sight		26.6	156.9			Continue local hold
79:28:36	Start pitch rate for 2nd control point landmark sighting	59.0	-11.3	160.7	5.0	0.0	0.0	-0.3	0.0	0.0	No line of sight		44.1	14.7	30.7	-173.9	-0.3 deg/sec pitch rate
79:33:05	Terminate pitch rate; maneuver to landmark sighting attitude	59.0	-12.2	146.8	5.0	0.0	0.0	-13.9	0.0	0.0	No line of sight		57.3	12.1	145.4	-174.7	Begin local hold
79:42:30	Acquire MSFN line of sight	58.8	-11.6	117.6	5.0	0.0	0.0	-42.5	0.0	0.0	25.6	-167.5	85.4	10.2			Continue local hold
80:06:52	Start pitch rate for pseudo landing site landmark sighting	58.1	0.7	43.8	5.0	0.0	0.0	-116.4	0.0	0.0	49.4	-7.0	157.0	26.8	30.5	-179.4	-0.3 deg/sec pitch rate
80:11:21	Terminate pitch rate; roll 180 deg	58.0	3.6	30.5	-62.1	0.0	180.0	162.9	0.0	180.0	129.8	173.1	119.5	-11.7	78.8	0.4	Begin inertial hold
80:18:41	Enter lunar umbra	57.9	7.8	8.4	-39.8	0.0	180.0	162.9	0.0	180.0	130.0	173.0	No line of sight				Continue inertial hold
80:32:00	Begin IMU realignment	57.8	12.0	-32.7	0.8	0.0	180.0	162.9	0.0	180.0	130.2	173.0	No line of sight				Continue inertial hold
80:54:50	Lose MSFN line of sight	58.5	6.5	-101.9	68.9	0.0	180.0	162.9	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
81:00:00	Maneuver to landmark sighting attitude	58.6	3.2	-118.4	5.0	0.0	0.0	82.2	0.0	0.0	No line of sight		No line of sight				Begin local hold
81:04:48	Enter sunlight	58.7	0.2	-132.7	5.0	0.0	0.0	67.7	0.0	0.0	No line of sight		26.3	156.6			Continue local hold
81:12:25	Start pitch rate for 1st control point landmark sighting	58.9	-4.7	-155.4	5.0	0.0	0.0	44.6	0.0	0.0	No line of sight		10.3	99.2	33.7	156.8	-0.3 deg/sec pitch rate
81:16:54	Terminate pitch rate; maneuver to landmark sighting attitude	59.0	-7.2	-168.9	5.0	0.0	0.0	31.0	0.0	0.0	No line of sight		15.6	40.9	147.8	160.9	Begin local hold
81:26:53	Start pitch rate for 2nd control point landmark sighting	59.1	-11.3	160.7	5.0	0.0	0.0	0.7	0.0	0.0	No line of sight		43.1	14.9	30.8	-173.3	-0.3 deg/sec pitch rate
81:31:22	Terminate pitch rate; maneuver to landmark sighting attitude	59.0	-12.1	146.8	5.0	0.0	0.0	-12.8	0.0	0.0	No line of sight		56.4	12.2	144.9	-169.9	Begin local hold
81:40:51	Acquire MSFN line of sight	58.8	-11.6	117.2	5.0	0.0	0.0	-41.7	0.0	0.0	25.4	-167.5	84.6	10.2			Continue local hold
81:44:48	Start pitch rate for 3rd control point landmark sighting	58.7	-10.6	105.1	5.0	0.0	0.0	-53.6	0.0	0.0	13.8	-157.5	96.4	10.2	30.8	169.5	-0.3 deg/sec pitch rate
81:49:17	Terminate pitch rate; maneuver to landmark sighting attitude	58.6	-8.8	91.4	5.0	0.0	0.0	-67.2	0.0	0.0	5.3	-81.3	109.8	10.8	145.2	176.4	Begin local hold
82:05:08	Start pitch rate for pseudo landing site landmark sighting	58.0	0.5	43.8	5.0	0.0	0.0	-115.3	0.0	0.0	49.4	-7.0	156.1	25.8	30.4	178.3	-0.3 deg/sec pitch rate

Table II. Spacecraft Attitude Data
(c) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles To Earth		Look Angles To Sun		Look Angles To Landmark		Comment
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
82:09:37	Terminate pitch rate; roll 180 deg	58.0	3.4	30.5	-62.1	0.0	180.0	164.0	0.0	180.0	129.8	173.1	120.5	-11.8	78.6	-1.6	Begin inertial hold
82:17:17	Enter lunar umbra	57.9	7.7	7.4	-38.8	0.0	180.0	164.0	0.0	180.0	130.0	173.1	No line of sight				Continue inertial hold
82:30:00	Begin IMU realignment	57.9	12.0	-31.5	-0.3	0.0	180.0	164.0	0.0	180.0	130.3	173.1	No line of sight				Continue inertial hold
82:52:49	Lose MSFN line of sight	58.4	6.8	-102.1	69.1	0.0	180.0	164.0	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
83:00:00	Maneuver to landmark sighting attitude	58.7	2.3	-123.6	5.0	0.0	0.0	78.1	0.0	0.0	No line of sight		No line of sight				Begin local hold
83:03:24	Enter sunlight	58.8	0.2	-133.7	5.0	0.0	0.0	67.7	0.0	0.0	No line of sight		26.7	156.7			Continue local hold
83:10:42	Start pitch rate for 1st control point landmark sighting	59.0	-4.5	-155.4	5.0	0.0	0.0	45.7	0.0	0.0	No line of sight		10.5	104.6	33.3	158.6	-0.3 deg/sec pitch rate
83:15:11	Terminate pitch rate; maneuver to landmark sighting attitude	59.0	-7.0	-168.9	5.0	0.0	0.0	32.1	0.0	0.0	No line of sight		14.9	43.3	147.6	162.4	Begin local hold
83:25:09	Start pitch rate for 2nd control point landmark sighting	59.1	-11.2	160.7	5.0	0.0	0.0	1.8	0.0	0.0	No line of sight		42.2	15.2	30.8	-172.7	-0.3 deg/sec pitch rate
83:29:38	Terminate pitch rate; maneuver to landmark sighting attitude	59.0	-12.1	146.8	5.0	0.0	0.0	-11.8	0.0	0.0	No line of sight		55.4	12.3	144.8	-169.0	Begin local hold
83:39:13	Acquire MSFN line of sight	58.9	-11.7	116.9	5.0	0.0	0.0	-40.8	0.0	0.0	25.0	-167.5	84.0	10.2			Continue local hold
83:43:05	Start pitch rate for 3rd control point landmark sighting	58.7	-10.7	105.1	5.0	0.0	0.0	-52.5	0.0	0.0	13.8	-157.7	95.4	10.2	30.9	168.2	-0.3 deg/sec pitch rate
83:47:34	Terminate pitch rate; maneuver to landmark sighting attitude	58.6	-8.9	91.4	5.0	0.0	0.0	-66.1	0.0	0.0	5.3	-80.9	108.8	10.7	145.1	169.3	Begin local hold
84:03:24	Start pitch rate for pseudo landing site landmark sighting	58.1	0.3	43.8	5.0	0.0	0.0	-114.2	0.0	0.0	49.4	-6.9	155.2	24.8	30.4	175.9	-0.3 deg/sec pitch rate
84:07:53	Terminate pitch rate; roll 180 deg	58.0	3.2	30.5	-62.1	0.0	180.0	165.1	0.0	180.0	129.8	173.2	121.5	-11.9	78.3	-3.7	Begin inertial hold
84:15:54	Enter lunar umbra	57.9	7.8	6.4	-37.8	0.0	180.0	165.1	0.0	180.0	130.0	173.2	No line of sight				Continue inertial hold
84:25:00	Begin IMU realignment	57.8	11.3	-21.6	-10.1	0.0	180.0	165.1	0.0	180.0	130.2	173.2	No line of sight				Continue inertial hold
84:45:00	Maneuver to darkside and solar corona photography attitude	58.2	9.7	-83.6	-20.0	0.0	180.0	94.4	0.0	180.0	158.0	14.0	No line of sight				Begin local hold
84:51:14	Lose MSFN line of sight	58.4	6.8	-102.5	-20.0	0.0	180.0	75.5	0.0	180.0	No line of sight		No line of sight				Continue local hold
85:00:00	Maneuver to orbital navigation photography attitude	58.7	1.4	-128.7	-70.0	0.0	180.0	-1.1	0.0	180.0	No line of sight		No line of sight				Begin local hold
85:02:00	Enter sunlight	58.8	0.1	-134.7	-70.0	0.0	180.0	-7.2	0.0	180.0	No line of sight		51.0	-166.9			Continue local hold
85:37:00	Pitch 40 deg; roll 180 deg; continue orbital navigation photography	58.8	-11.9	118.6	-110.0	0.0	0.0	-153.3	0.0	0.0	No line of sight		160.9	147.6			Begin local hold
85:37:06	Acquire MSFN line of sight	58.8	-11.9	118.3	-110.0	0.0	0.0	-153.6	0.0	0.0	90.3	-5.1	126.3	167.5			Continue local hold
86:14:30	Enter lunar umbra	57.9	7.8	5.4	-110.0	0.0	0.0	92.9	0.0	0.0	156.0	-167.0	No line of sight				Continue local hold
86:16:00	Roll 180 deg; pitch 57.5 deg	57.8	8.5	0.8	-52.5	0.0	180.0	145.9	0.0	180.0	150.1	169.6	No line of sight				Begin inertial hold
86:30:00	Begin IMU realignment	57.9	12.3	-42.4	-10.0	0.0	180.0	145.9	0.0	180.0	150.4	169.5	No line of sight				Continue inertial hold
86:49:35	Lose MSFN line of sight	58.4	6.8	-102.7	49.5	0.0	180.0	145.9	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
86:50:00	Maneuver to lunar observation attitude	58.4	6.6	-104.0	-45.0	0.0	180.0	50.1	0.0	180.0	No line of sight		No line of sight				Begin local hold
87:00:37	Enter sunlight	58.7	0.1	-135.7	-45.0	0.0	180.0	17.9	0.0	180.0	No line of sight		27.1	-157.1			Continue local hold
87:35:27	Acquire MSFN line of sight	58.8	-11.8	117.9	-45.0	0.0	180.0	-87.8	0.0	180.0	25.1	167.8	130.1	-166.7			Continue local hold
87:53:00	Terminate local attitude hold	58.3	-4.5	64.5	-45.0	0.0	180.0	-141.0	0.0	180.0	78.0	174.8	169.1	-68.0			Begin inertial hold
88:13:05	Enter lunar umbra; begin IMU realignment	57.9	7.7	4.7	15.7	0.0	180.0	-141.0	0.0	180.0	78.5	174.8	No line of sight				Continue inertial hold

Table II. Spacecraft Attitude Data
(c) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles To Earth		Look Angles To Sun		Look Angles To Landmark		Comment
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
88:47:53	Lose MSFN line of sight	58.4	7.0	-103.0	121.7	0.0	180.0	-141.0	0.0	180.0	No line of sight		No line of sight				Continue inertial hold
88:50:00	Maneuver to TEI burn attitude	58.5	5.8	-109.2	-48.9	0.6	-179.9	42.0	0.6	179.9	No line of sight		No line of sight				Begin inertial hold
88:59:12	Enter sunlight	58.7	0.1	-136.7	-21.0	0.6	-179.9	42.0	0.6	179.9	No line of sight		9.6	-97.0			Continue inertial hold
89:04:02	Initiate TEI burn	58.8	-3.0	-151.0	-6.3	0.6	-179.9	42.0	0.6	179.9	No line of sight		9.6	-97.0			Continue inertial hold

Table II. Spacecraft Attitude Data
(d) Transearth

Mission Time (hr:min:sec)	Event	Geocentric Inertial Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		Comments
		Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
89:06:53	TEI cutoff	-174.6	0.1	57.0	-52.5	0.1	-179.7	No line of sight		0.0	-177.8	95.6	-170.0	Acquire lunar surface in window, inertial hold
90:00:00	Orient for IMU alignment	-174.6	0.1	57.0	-52.5	0.1	-179.7	11.1	26.6	95.5	0.0	95.6	-170.0	0.5 deg/sec maneuver rate
90:10:00	Perform IMU alignment	-174.6	0.1	57.0	-52.5	0.1	-179.7	11.2	26.5	99.6	0.0	95.7	-170.0	Continue inertial hold
90:30:00	Complete IMU alignment; orient for navigation sightings	-174.6	0.1	57.0	-52.5	0.1	-179.7	11.2	26.4	105.5	0.0	95.7	-170.0	0.5 deg/sec maneuver rate
90:40:00	Perform SLL navigation sightings	-141.3	44.0	-139.8	-105.3	-2.9	-4.1	42.8	0.0	54.8	-177.6	148.0	18.8	Begin inertial hold
92:00:00	Complete navigation sightings; orient for PTC	-141.3	44.0	-139.8	-105.3	-2.9	-4.1	42.7	0.0	63.4	-177.0	148.1	18.8	0.5 deg/sec maneuver rate
92:15:00	Start PTC tumble mode	81.2	-66.3	-144.8	43.4	10.2	47.1	106.6	135.0	145.1	-32.7	0.0	-53.7	Yaw at 0.2 deg/sec
97:10:00	Complete PTC; orient for navigation sightings	50.7	-10.0	-166.4	90.1	-29.4	55.9	136.8	172.1	91.2	-56.9	59.9	89.8	0.5 deg/sec maneuver rate
97:20:00	Perform SLH navigation sightings	-124.2	55.3	-150.5	-121.0	-4.8	-2.7	58.3	0.0	57.5	180.0	163.9	23.1	Begin inertial hold
98:00:00	Complete navigation sightings; orient for IMU alignment	-124.2	55.3	-150.5	-121.0	-4.8	-2.7	58.4	0.0	57.9	180.0	163.9	23.1	0.5 deg/sec maneuver rate
98:10:00	Perform IMU alignment	-124.2	55.3	-150.5	-121.0	-4.8	-2.7	58.4	0.0	58.0	-179.9	163.9	23.1	Continue inertial hold
98:30:00	Complete IMU alignment	-124.2	55.3	-150.5	-121.0	-4.8	-2.7	58.4	0.0	58.2	-179.9	163.9	23.1	Continue inertial hold
99:00:00	Initiate midcourse correction	-124.2	55.3	-150.5	-121.0	-4.8	-2.7	58.5	0.0	58.5	-179.9	163.9	23.2	Continue inertial hold
99:10:00	Orient for navigation sightings	-124.2	55.3	-150.5	-121.0	-4.8	-2.7	58.5	0.0	58.7	-179.9	163.9	23.2	0.5 deg/sec maneuver rate
99:20:00	Perform SEH navigation sightings	153.1	-37.1	-130.1	-4.8	-1.4	4.8	57.5	180.0	174.6	-167.0	49.6	9.8	Begin inertial hold
99:50:00	Complete navigation sightings; orient for PTC	153.1	-37.1	-130.1	-4.8	-1.4	4.8	57.5	180.0	174.9	-165.9	49.6	9.8	0.5 deg/sec maneuver rate
100:06:00	Start PTC	45.9	19.9	-76.8	123.6	-44.3	165.6	130.6	112.0	66.5	-140.9	90.0	0.0	Roll at 0.2 deg/sec
106:10:00	Complete PTC; orient for navigation sightings	45.9	19.9	-76.8	123.6	-44.3	165.6	130.7	111.3	65.2	-139.3	89.8	-0.2	0.5 deg/sec maneuver rate
106:20:00	Perform SLH navigation sightings	5.3	-8.4	-60.2	120.6	4.6	176.7	177.7	179.9	57.5	180.0	76.1	-6.2	Begin inertial hold
106:50:00	Complete navigation sightings; orient for PTC	5.3	-8.4	-60.2	120.6	4.6	176.7	177.8	180.0	57.5	180.0	75.9	-6.1	0.5 deg/sec maneuver rate
107:05:00	Start PTC	45.8	20.1	-77.0	123.8	-44.3	165.6	130.7	111.6	64.9	-138.8	90.0	0.0	Roll at 0.2 deg/sec
116:00:00	Complete PTC; orient for navigation sightings	45.8	20.1	-137.0	123.8	-44.3	105.6	130.9	170.2	63.9	-77.3	89.8	59.7	0.5 deg/sec maneuver rate
116:10:00	Perform SLH navigation sightings	6.3	-10.1	-60.2	118.7	4.7	176.7	179.3	0.0	57.5	180.0	73.8	-6.1	Begin inertial hold
117:00:00	Complete navigation sightings; orient for IMU alignment	6.3	-10.1	-60.2	118.7	4.7	176.7	179.0	0.0	57.9	180.0	73.8	-6.1	0.5 deg/sec maneuver rate
117:10:00	Perform IMU alignment	6.3	-10.1	-60.2	118.7	4.7	176.7	179.0	0.0	58.0	180.0	73.8	-6.1	Continue inertial hold
117:30:00	Complete IMU alignment	6.3	10.1	-60.2	118.7	4.7	176.7	179.0	0.0	58.1	180.0	73.7	6.1	Continue inertial hold
118:00:00	Initiate midcourse correction	6.3	10.1	-60.2	118.7	4.7	176.7	178.9	0.0	58.3	180.0	73.7	6.1	Continue inertial hold
118:10:00	Orient for navigation sightings	6.3	10.1	-60.2	118.7	4.7	176.7	179.9	0.0	58.4	180.0	73.7	6.1	0.5 deg/sec maneuver rate
118:20:00	Perform SEH navigation sightings	-128.5	54.1	33.4	-118.3	-5.2	177.9	57.8	180.0	66.1	0.0	162.2	-160.4	Begin inertial hold
118:50:00	Complete navigation sightings; orient for PTC	-128.5	54.1	33.4	-118.3	-5.2	177.9	57.9	180.0	66.2	0.0	162.2	-160.4	0.5 deg/sec maneuver rate
119:05:00	Start PTC	45.7	20.4	-77.3	124.3	-44.4	165.5	130.9	110.3	63.3	-136.4	90.0	0.0	Roll at 0.2 deg/sec
128:50:00	Complete PTC; orient for navigation sightings	45.7	20.4	-77.3	124.3	-44.4	-74.5	131.2	-11.7	62.3	105.2	89.7	-120.3	0.5 deg/sec maneuver rate

Table II. Spacecraft Attitude Data
(d) Transearth (Continued)

Mission Time (hr:min:sec)	Event	Geocentric Inertial Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		Comments
		Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	
129:00:00	Perform SEH navigation sightings	141.4	-32.5	-143.7	-0.6	-11.2	-1.6	57.7	179.8	167.5	-62.0	50.1	25.3	Begin inertial hold
129:30:00	Complete navigation sightings; orient for SLH navigation sightings	141.4	-32.5	-143.7	-0.6	-11.2	-1.6	57.7	179.7	167.5	-61.6	50.2	25.3	0.5 deg/sec maneuver rate
129:40:00	Perform SLH navigation sightings	7.5	-12.1	-60.0	116.4	4.7	176.9	174.8	0.0	57.5	180.0	70.9	-6.2	Begin inertial hold
130:10:00	Complete navigation sightings; orient for PTC	7.5	-12.1	-60.0	116.4	4.7	176.9	174.9	0.0	57.8	180.0	70.9	-6.2	0.5 deg/sec maneuver rate
130:25:00	Start PTC	45.3	20.7	-77.6	124.8	-44.2	165.5	131.4	108.6	61.7	-134.1	90.0	0.0	Roll at 0.2 deg/sec
140:00:00	Complete PTC; orient for navigation sightings	45.3	20.7	-17.6	124.8	-44.2	-134.5	131.7	45.8	60.6	167.8	89.7	-60.3	0.5 deg/sec maneuver rate
140:10:00	Perform SLH navigation sightings	8.8	-13.9	-59.6	114.1	4.7	177.2	170.3	0.0	57.5	180.0	68.2	-6.4	Begin inertial hold
141:00:00	Complete navigation sightings; orient for IMU alignment	8.8	-13.9	-59.6	114.1	4.7	177.2	170.0	0.0	57.3	180.0	68.2	-6.4	0.5 deg/sec maneuver rate
141:10:00	Perform IMU alignment	8.8	-13.9	-59.6	114.1	4.7	177.2	170.0	0.0	57.3	180.0	68.2	-6.4	Continue inertial hold
141:30:00	Complete IMU alignment	8.8	-13.9	-59.6	114.1	4.7	177.2	169.9	-0.1	57.2	180.0	68.1	-6.4	Continue inertial hold
142:00:00	Initiate midcourse correction	8.8	-13.9	-59.6	114.1	4.7	177.2	169.8	-0.1	57.0	180.0	68.1	-6.4	Continue inertial hold
142:10:00	Orient for navigation sightings	8.8	-13.9	-59.6	114.1	4.7	177.2	169.7	-0.1	57.0	180.0	68.1	-6.4	0.5 deg/sec maneuver rate
142:20:00	Perform SEH navigation sightings	-134.6	51.2	38.3	-113.5	-5.2	178.4	57.8	180.0	75.6	0.0	158.6	-163.2	Begin inertial hold
142:50:00	Complete navigation sightings; orient for PTC	-134.6	51.2	38.3	-113.5	-5.2	178.4	57.9	180.0	75.7	0.0	158.6	-163.1	0.5 deg/sec maneuver rate
143:05:00	Start PTC	45.0	21.0	-77.9	125.4	-44.1	165.5	131.8	105.4	59.9	-130.9	90.0	0.0	Roll at 0.2 deg/sec
148:50:00	Complete PTC; orient for navigation sightings	45.0	21.0	-42.1	125.4	-44.1	-74.5	132.0	-17.1	59.0	110.7	89.8	-120.2	0.5 deg/sec maneuver rate
149:00:00	Perform SEH navigation sightings	133.1	-28.8	-154.4	3.2	-18.3	-7.0	57.1	179.6	157.3	-43.8	50.9	37.9	Begin inertial hold
149:50:00	Complete navigation sightings; orient for PTC	133.1	-28.8	-154.4	3.2	-18.3	-7.0	56.8	179.4	157.2	-43.2	50.9	37.9	0.5 deg/sec maneuver rate
150:05:00	Start PTC	44.8	21.1	-78.0	125.7	-44.0	165.5	132.2	102.6	58.6	-128.6	90.0	0.0	Roll at 0.2 deg/sec
155:50:00	Complete PTC; orient for navigation sightings	44.8	21.1	102.0	125.7	-44.0	-14.5	132.4	-81.2	57.6	53.4	89.8	179.8	0.5 deg/sec maneuver rate
156:00:00	Perform SEH navigation sightings	149.2	-50.8	-128.8	6.7	6.6	8.3	57.5	180.0	158.8	10.6	39.1	0.0	Begin inertial hold
156:30:00	Reorient and perform SLL navigation sightings	11.8	-18.0	-58.6	109.1	4.5	177.8	158.8	0.0	57.5	180.0	62.6	-7.2	Begin inertial hold
157:00:00	Complete navigation sightings; orient for PTC	11.8	-18.0	-58.6	109.1	4.5	177.8	158.5	0.0	57.3	180.0	62.6	-7.2	0.5 deg/sec maneuver rate
157:15:00	Start PTC	45.6	21.5	-78.5	125.7	-44.8	165.3	131.6	97.8	57.9	-125.4	90.0	0.0	Roll at 0.2 deg/sec
167:30:00	Complete PTC; orient for IMU orientation determination	35.2	19.2	105.1	-125.7	38.4	175.8	139.9	-105.9	47.2	55.6	89.7	179.7	Change to entry REFSMMAT, 0.5 deg/sec maneuver rate
168:00:00	Complete IMU orientation determination; orient for IMU alignment	35.2	19.2	105.1	-125.7	38.4	175.8	139.2	-109.2	47.1	55.9	89.7	179.7	0.5 deg/sec maneuver rate
168:10:00	Perform IMU alignment	35.2	19.2	105.1	-125.7	38.4	175.8	138.9	-110.5	47.0	56.0	89.7	179.6	Continue inertial hold
168:30:00	Complete IMU alignment	35.2	19.2	105.1	-125.7	38.4	175.8	138.2	-113.4	46.9	56.3	89.7	179.6	Continue inertial hold
169:05:00	Initiate midcourse correction	35.2	19.2	105.1	-125.7	38.4	175.8	136.4	-119.4	46.7	56.7	89.7	179.6	Continue inertial hold
170:00:00	Perform IMU alignment	-72.3	62.4	-14.8	156.0	0.0	0.0	137.4	180.0	52.5	-1.8	164.8	-12.6	Performed in entry attitude, inertial hold
170:20:00	Complete IMU alignment	-72.3	62.4	-14.8	156.0	0.0	0.0	147.1	180.0	52.7	-1.8	164.8	-12.6	Continue inertial hold
170 48:32	Orient for CM/SM separation	-72.3	62.4	-14.8	156.0	0.0	0.0	179.8	-5.7	52.7	-1.8	164.8	-12.6	0.5 deg/sec maneuver rate
170:50:32	CM/SM separation	55.3	-2.2	-47.7	-87.3	45.0	0.0	68.2	-23.6	73.0	-160.0	64.6	-34.3	Yaw +45 deg
171:05:32	Entry	-72.3	62.4	-14.8	156.0	0.0	0.0	114.0	0.0	52.2	-1.7	164.7	-12.6	

Table III. C-prime Lunar Orbit Mission IMU Matrices; Launch Date December 21, 1968; 72 Degrees Launch Azimuth

Pre-Launch REFSMMAT

$$\begin{bmatrix} \overline{X} \\ \overline{Y} \\ \overline{Z} \end{bmatrix}_{IMU} = \begin{bmatrix} -0.81214345 & -0.30486116 & 0.49747632 \\ -0.33253554 & -0.45874422 & -0.87399866 \\ 0.47941956 & -0.83463367 & -0.27118908 \end{bmatrix}$$

$$\begin{matrix} \underline{X} & \underline{Y} & \underline{Z} \end{matrix}$$

LOI-2 REFSMMAT

$$\begin{bmatrix} \overline{X} \\ \overline{Y} \\ \overline{Z} \end{bmatrix}_{IMU} = \begin{bmatrix} -0.64877632 & 0.07638412 & -0.7571359 \\ -0.66111865 & -0.54928435 & 0.51108595 \\ -0.37684405 & 0.83213712 & 0.40686164 \end{bmatrix}$$

$$\begin{matrix} \underline{X} & \underline{Y} & \underline{Z} \end{matrix}$$

Entry REFSMMAT

$$\begin{bmatrix} \overline{X} \\ \overline{Y} \\ \overline{Z} \end{bmatrix}_{IMU} = \begin{bmatrix} -0.5310936 & -0.01691802 & 0.84714425 \\ -0.76132403 & 0.44838224 & -0.46833652 \\ -0.3719211 & -0.89368179 & -0.251013 \end{bmatrix}$$

$$\begin{matrix} \underline{X} & \underline{Y} & \underline{Z} \end{matrix}$$

Table IV. Scanning Telescope Sighting Targets

Launch Date: December 21, 1968

Landing Site: II-P-2

Type	Latitude	Longitude	Altitude (meters)
First control point landmark	4.200° S	164.300° W	0.0
Second control point landmark	12.500° S	151.500° E	0.0
Third control point landmark	8.500° S	96.000° E	0.0
Pseudo landing site landmark	2.570° N	35.000° E	-890.0

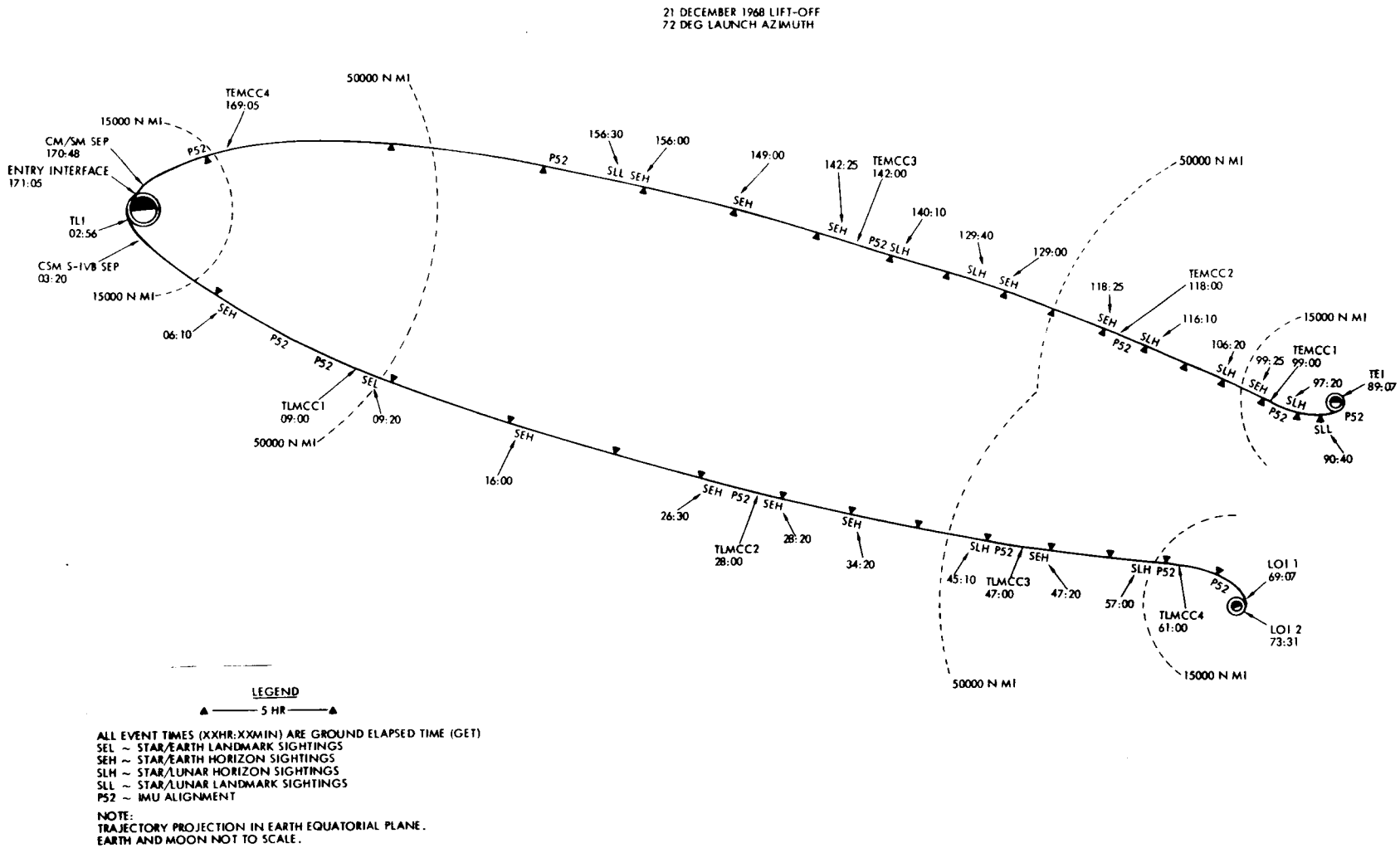


Figure 1. C-prime Lunar Orbit Mission Cislunar Trajectory and Event Profile

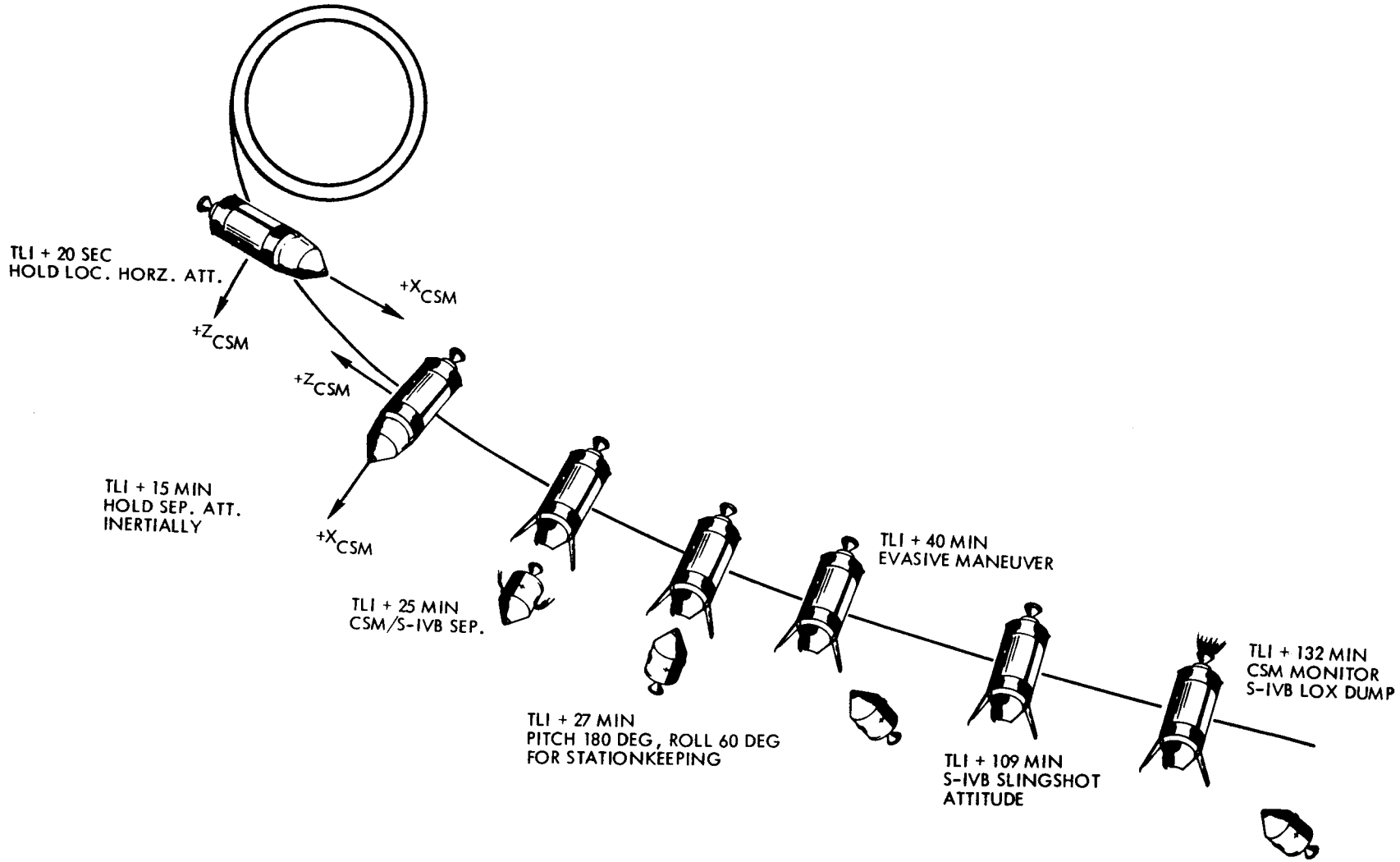
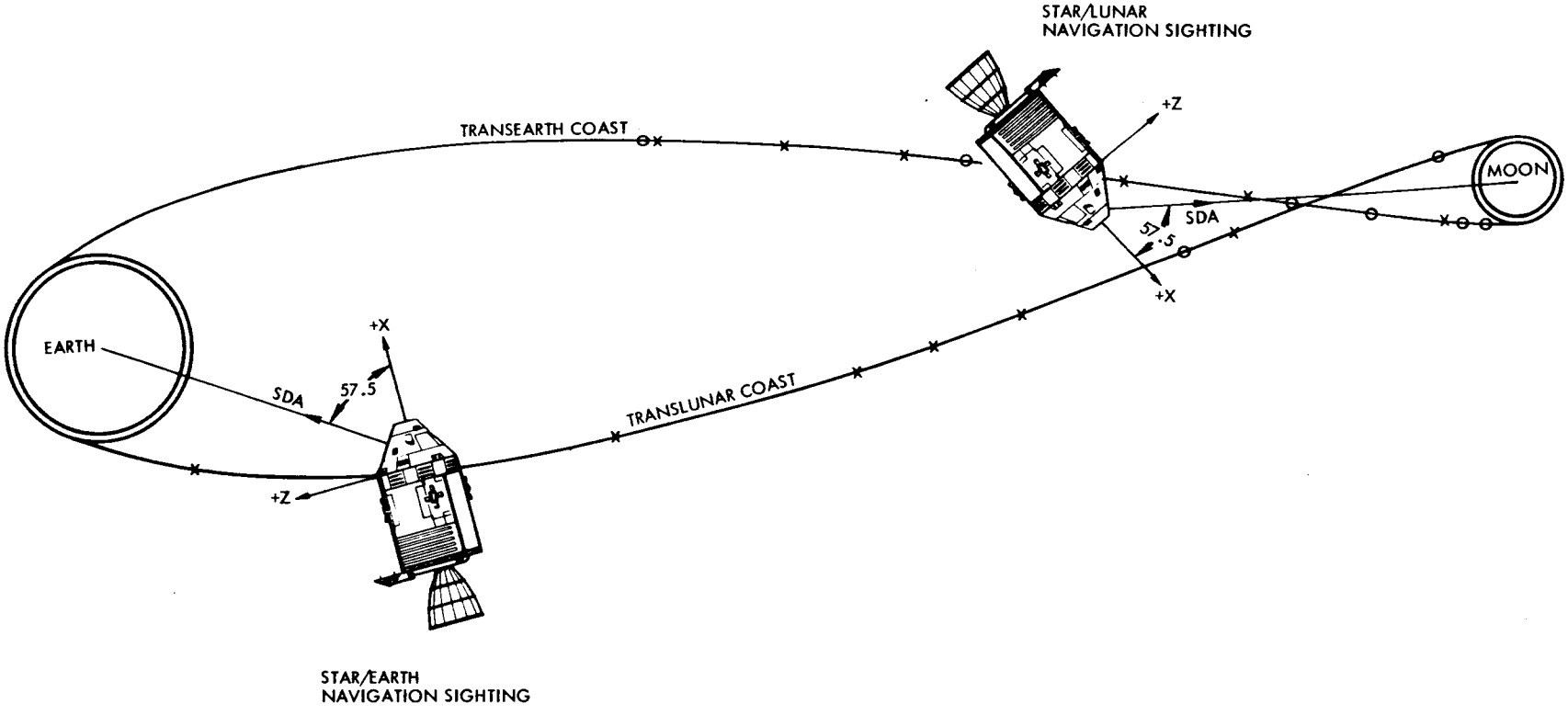


Figure 2. C-prime Lunar Orbit Mission Post-TLI Sequence of Events



LEGEND

X ~ STAR/EARTH NAVIGATION SIGHTING

O ~ STAR/LUNAR NAVIGATION SIGHTING

Figure 3. Cislunar Navigation Sighting Attitude Geometry

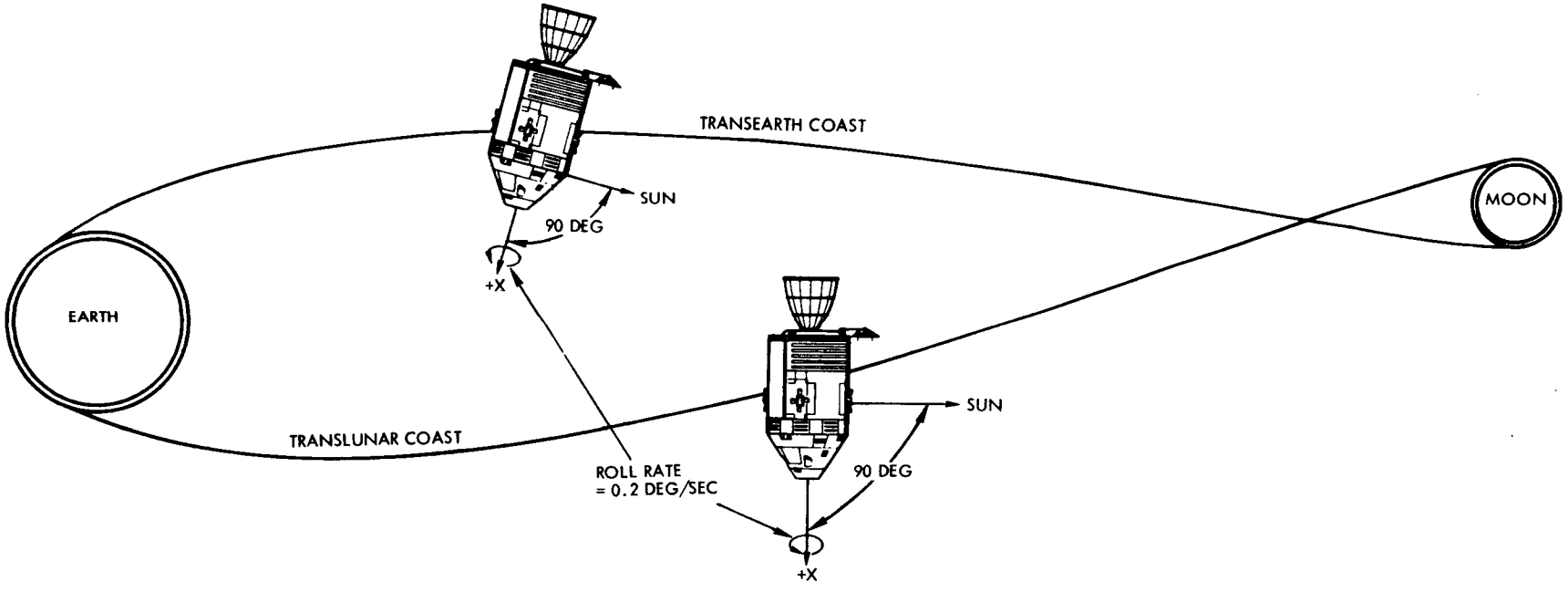


Figure 4. PTC Attitude Geometry

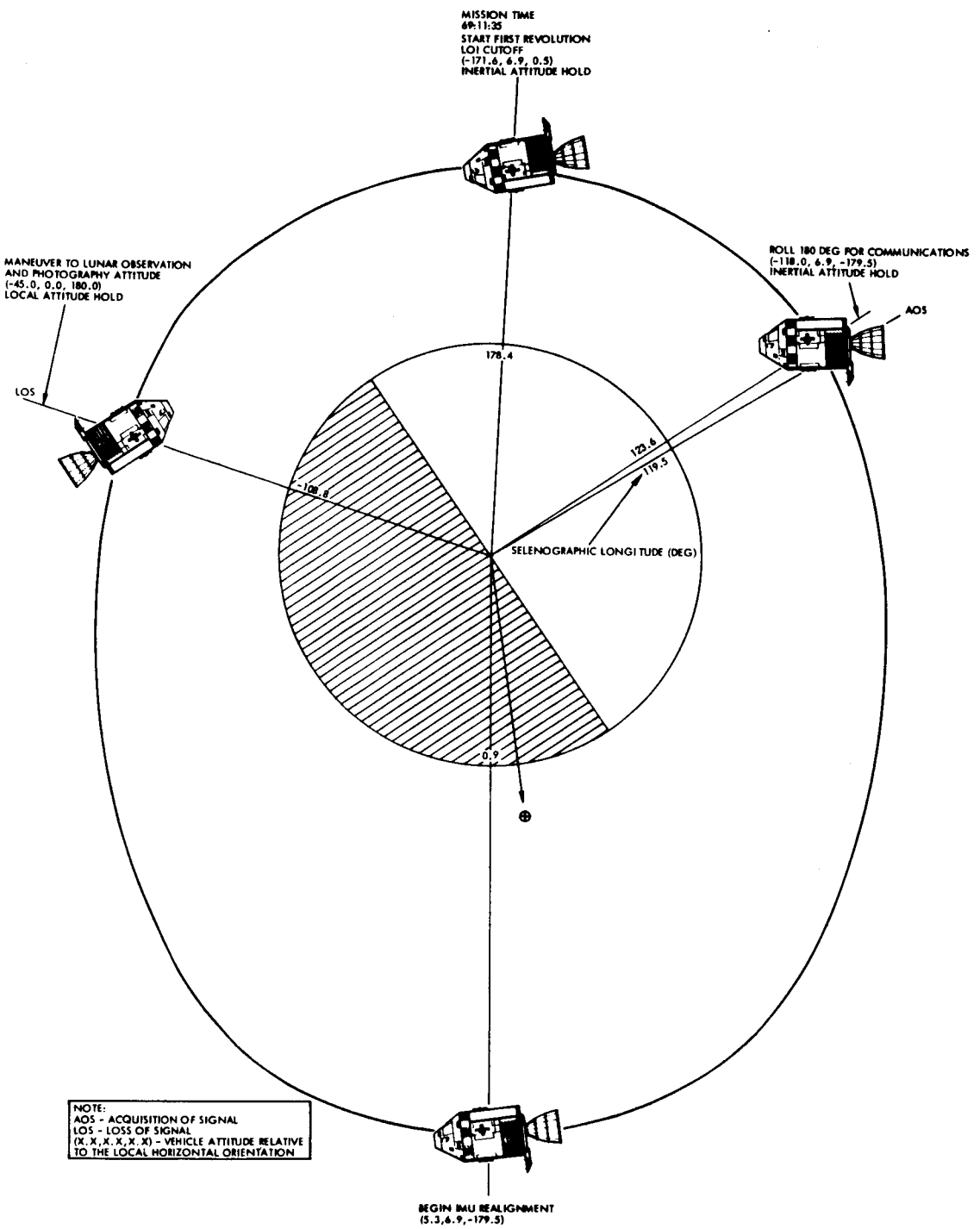


Figure 5. First Revolution Major Events and Attitudes

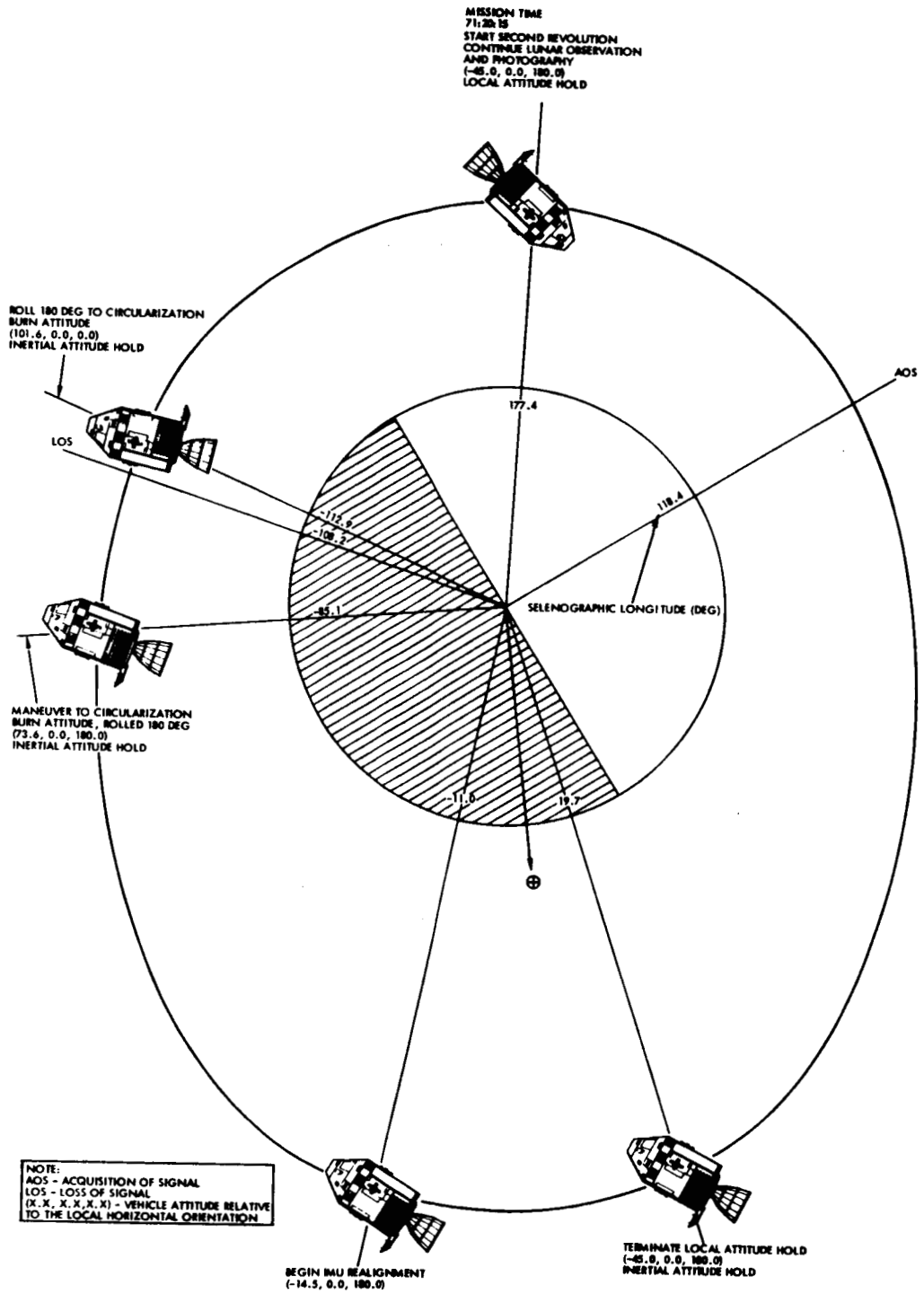


Figure 6. Second Revolution Major Events and Attitudes

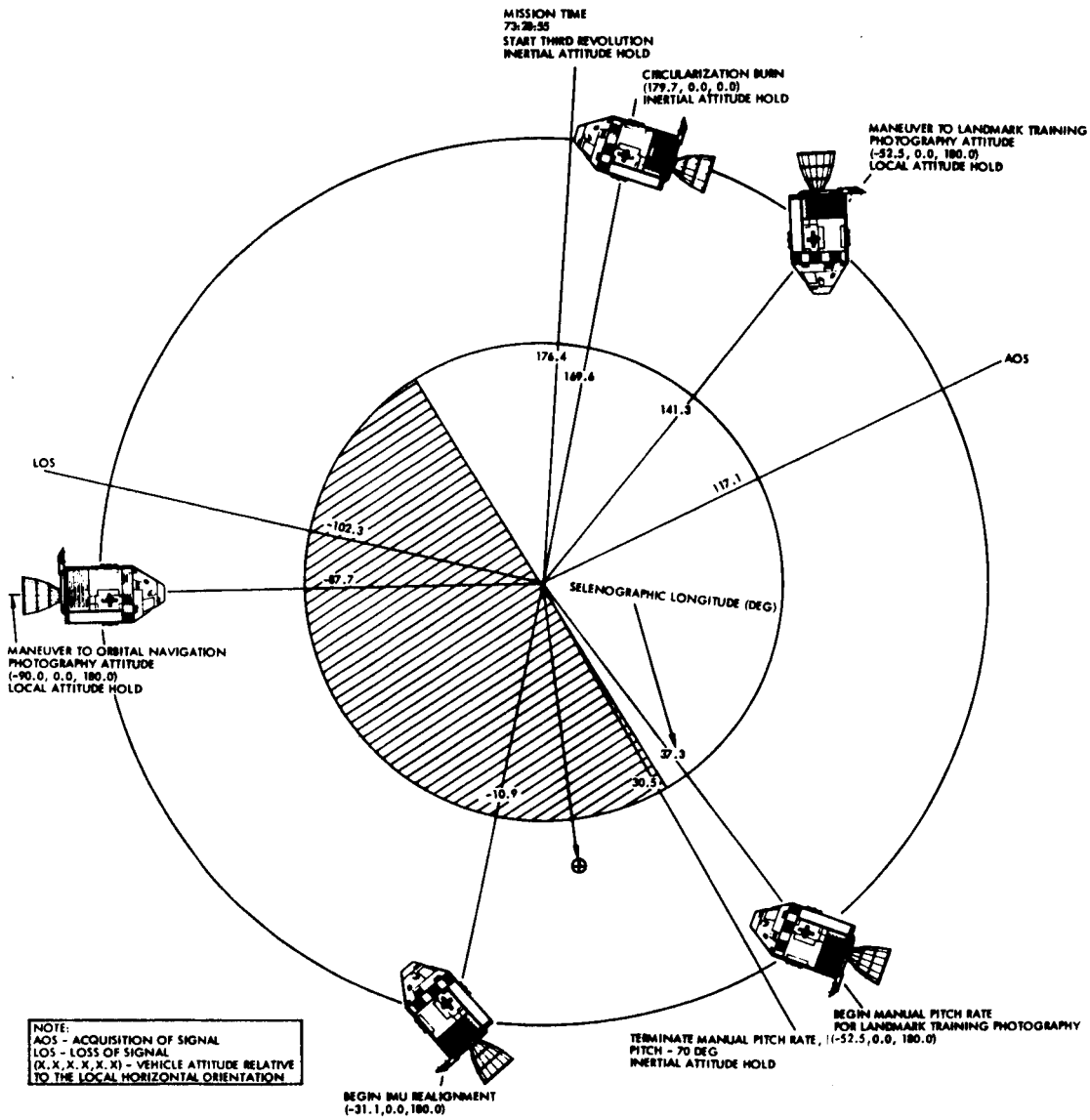


Figure 7. Third Revolution Major Events and Attitudes

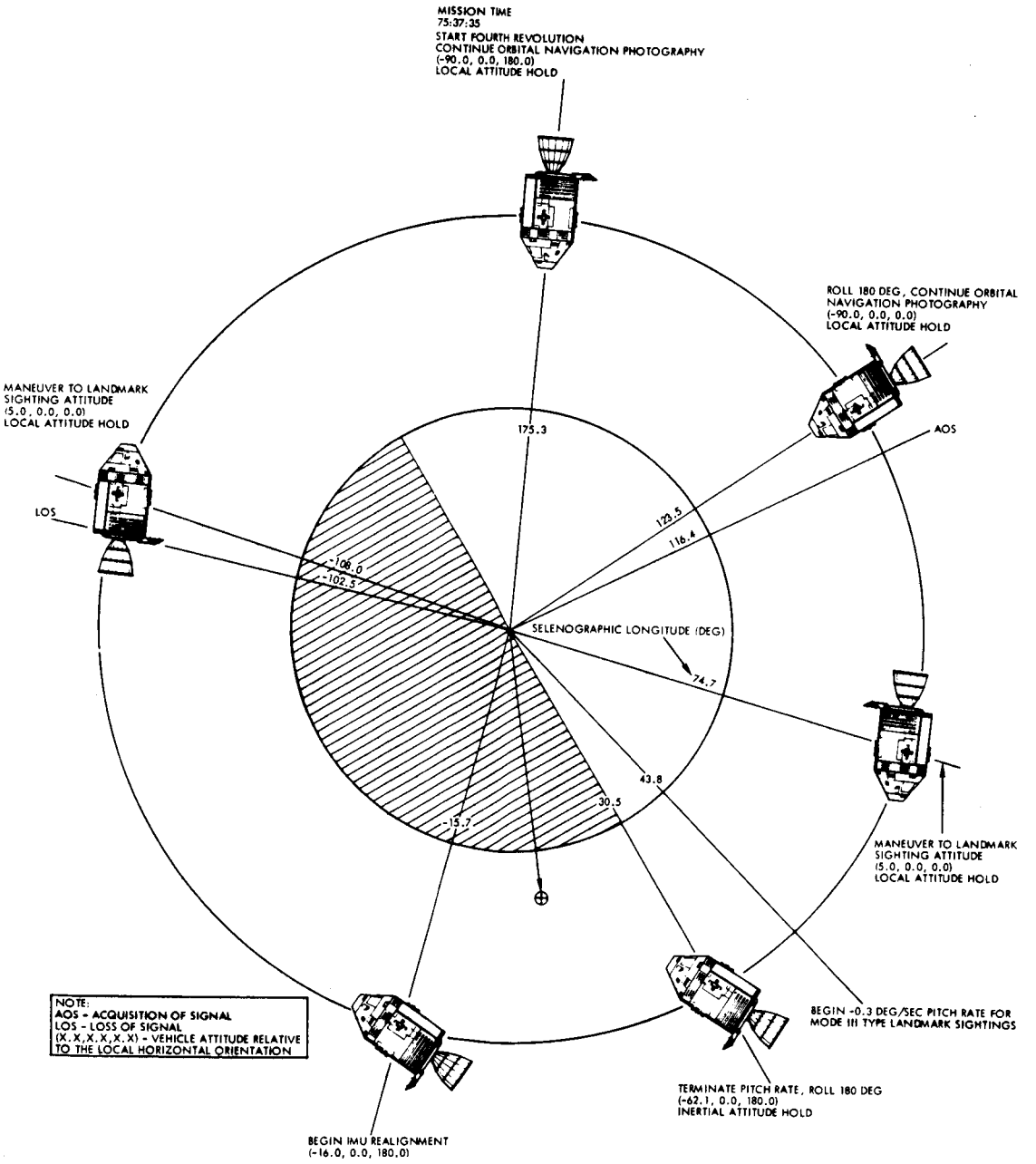


Figure 8. Fourth Revolution Major Events and Attitudes

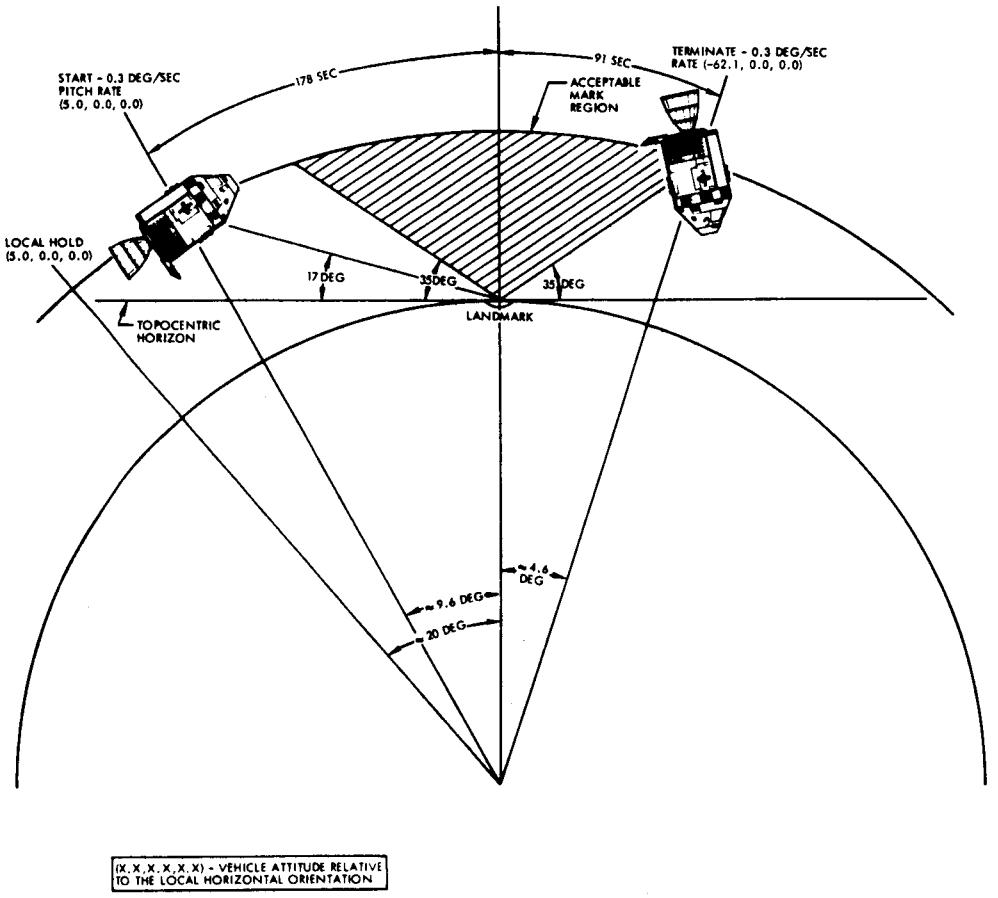


Figure 9. Mode III Type Landmark Sighting Attitude Sequence

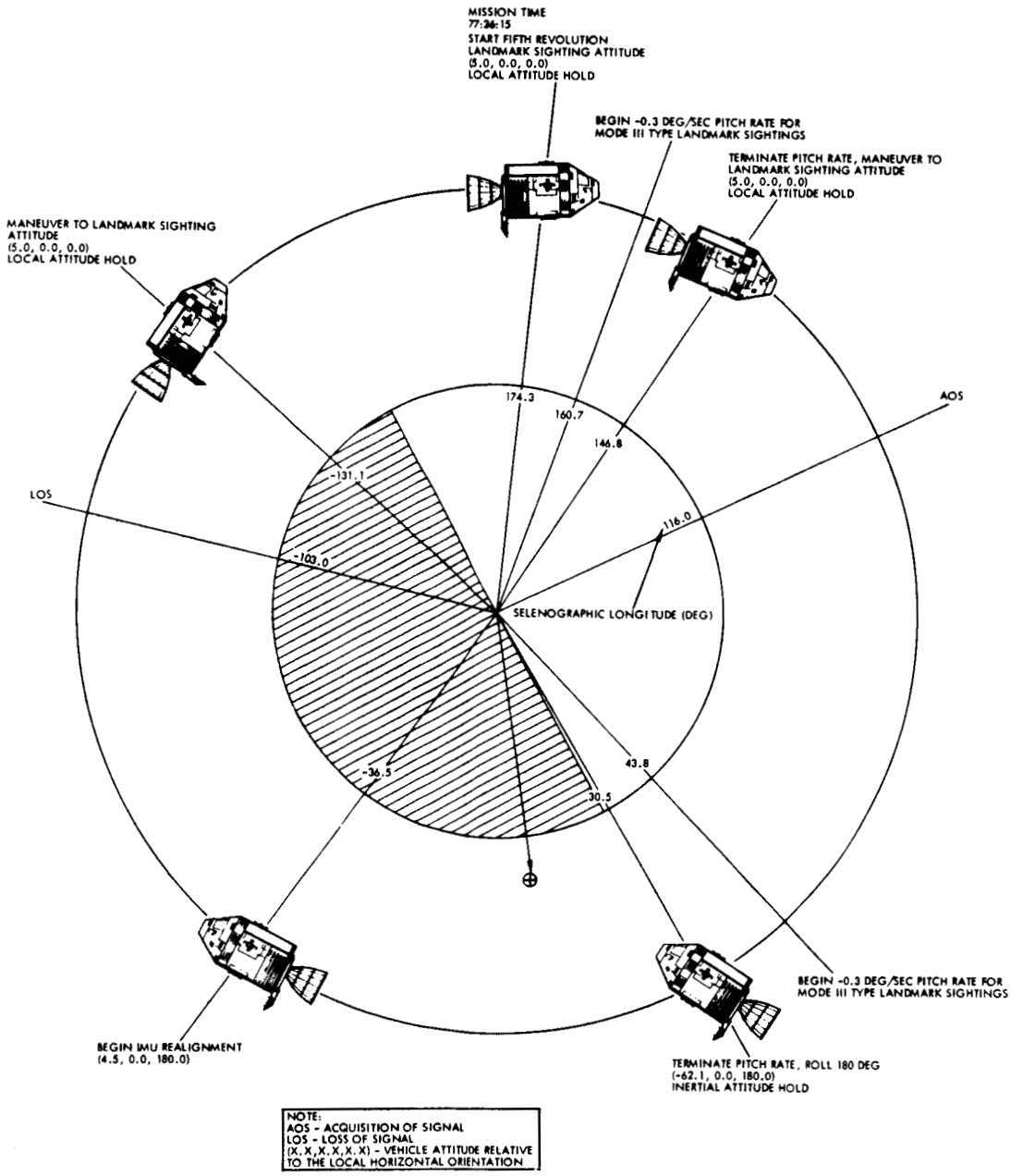


Figure 10. Fifth Revolution Major Events and Attitudes

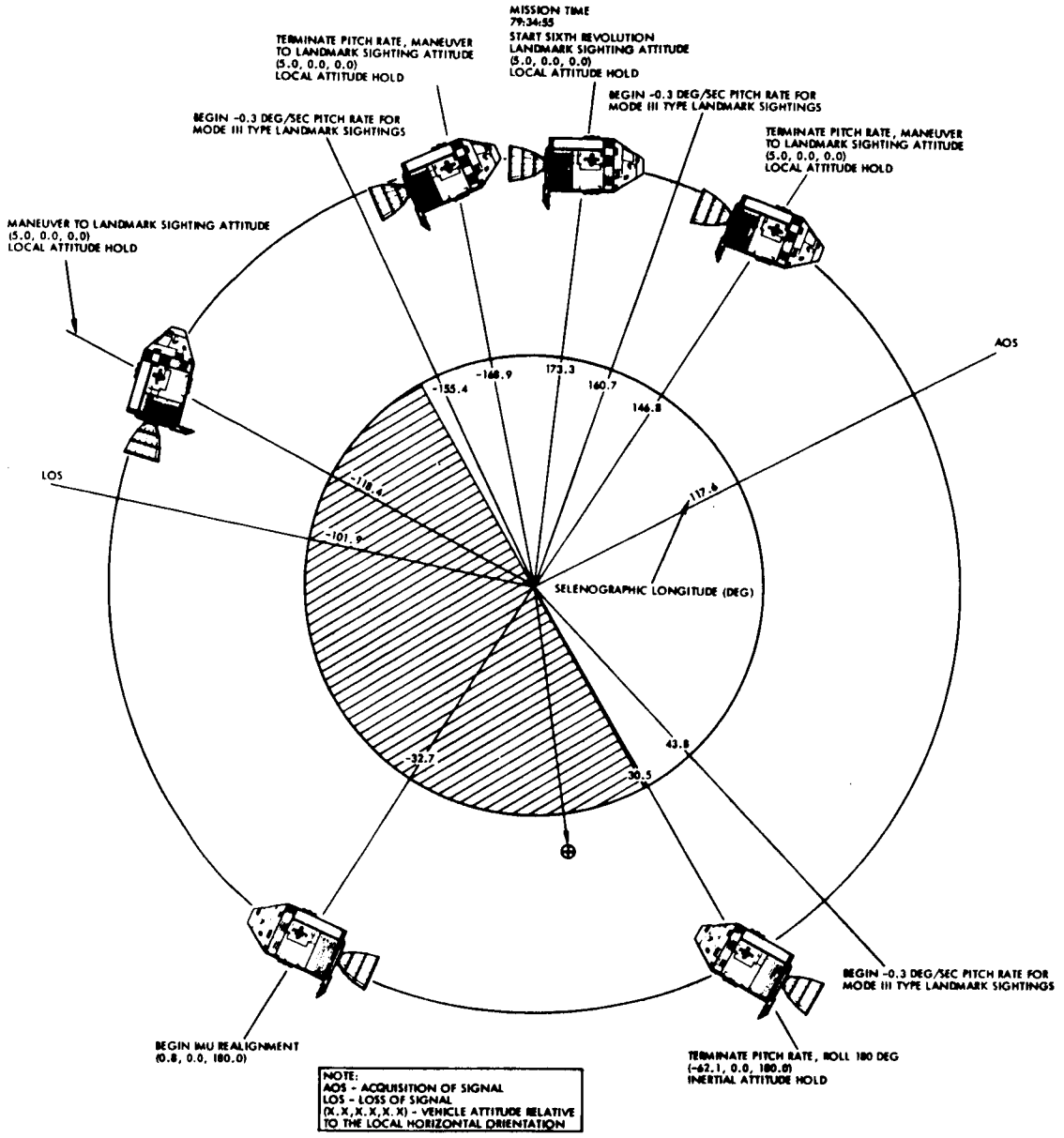


Figure 11. Sixth Revolution Major Events and Attitudes

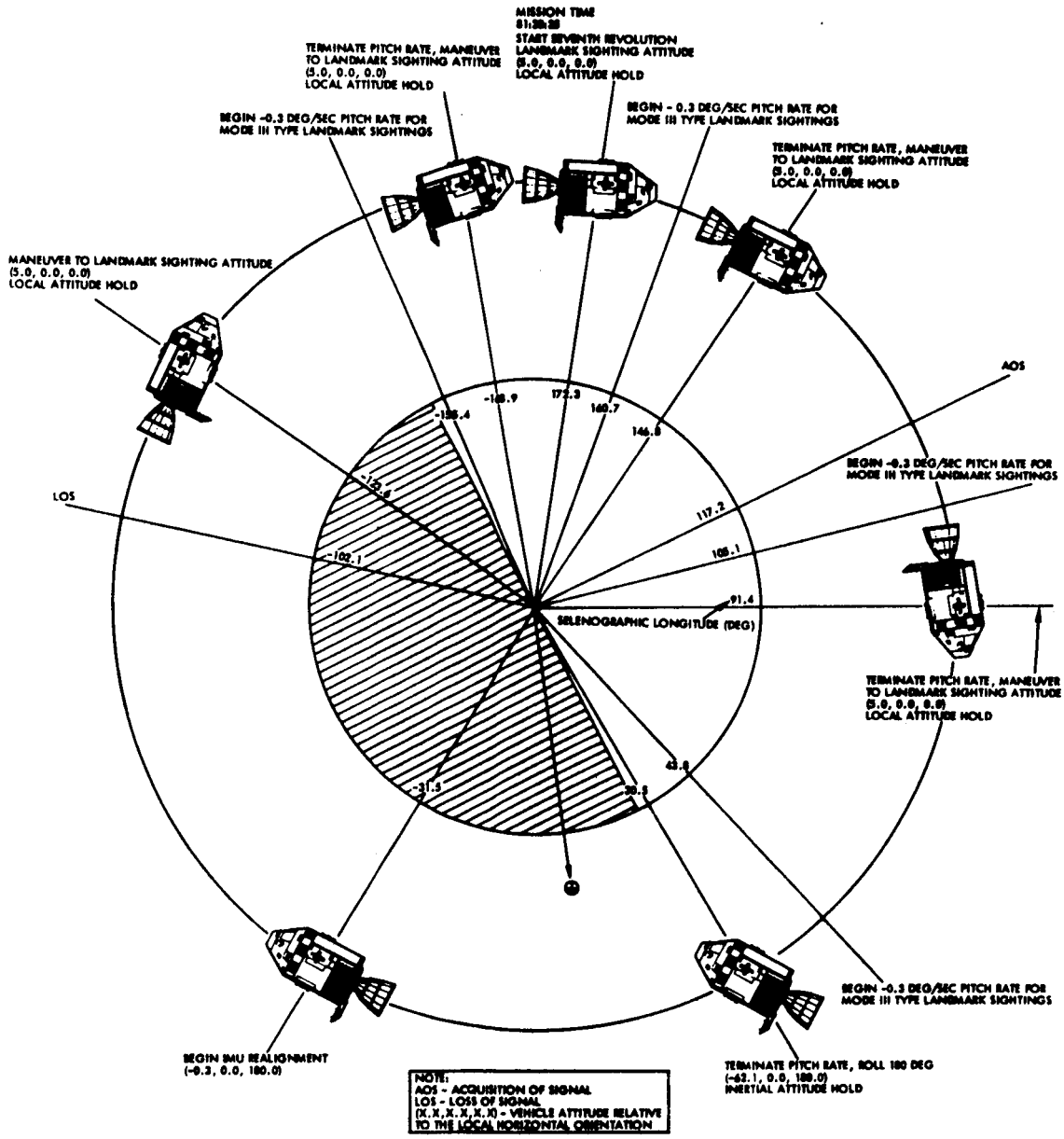


Figure 12. Seventh Revolution Major Events and Attitudes

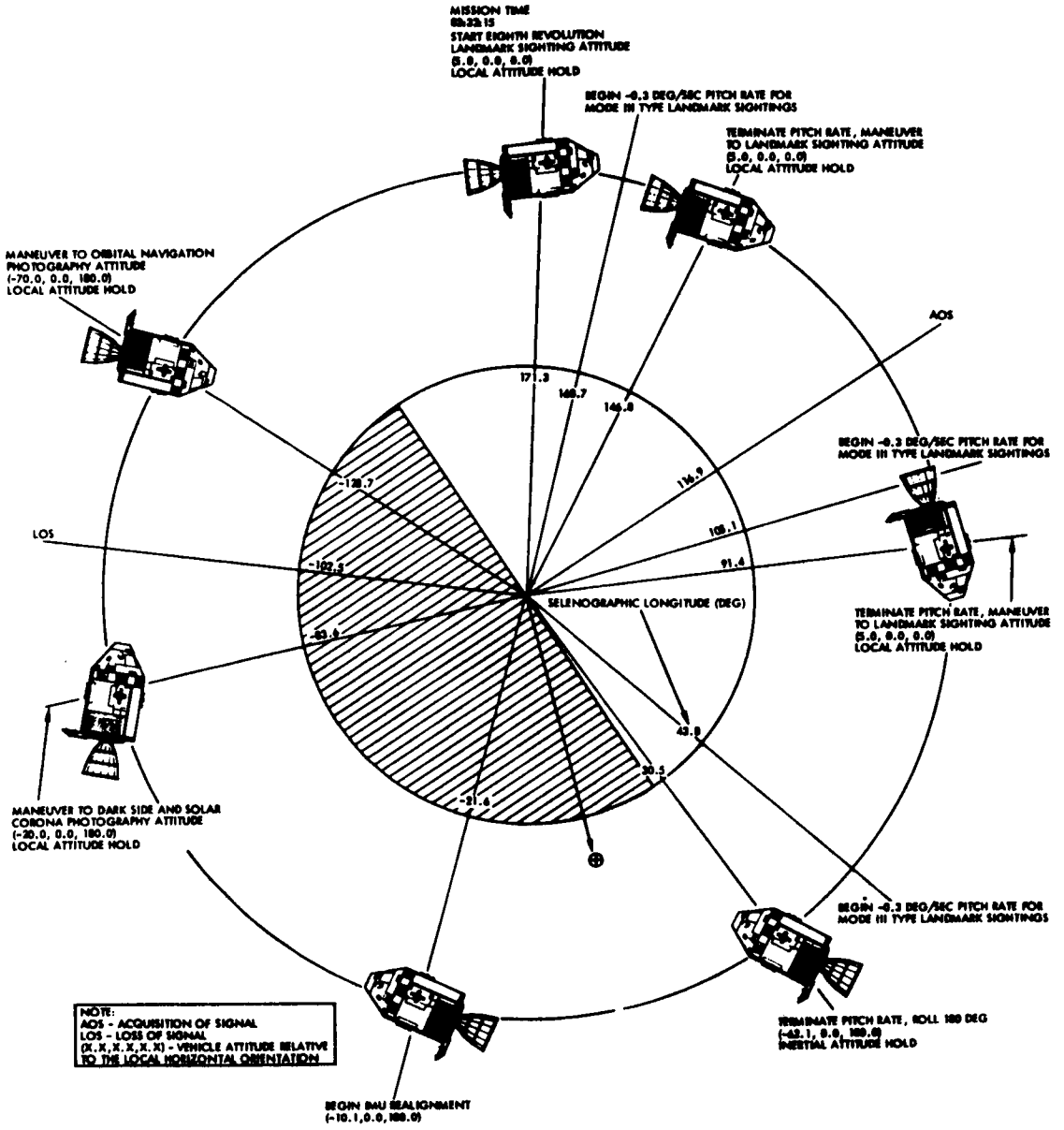


Figure 13. Eighth Revolution Major Events and Attitudes

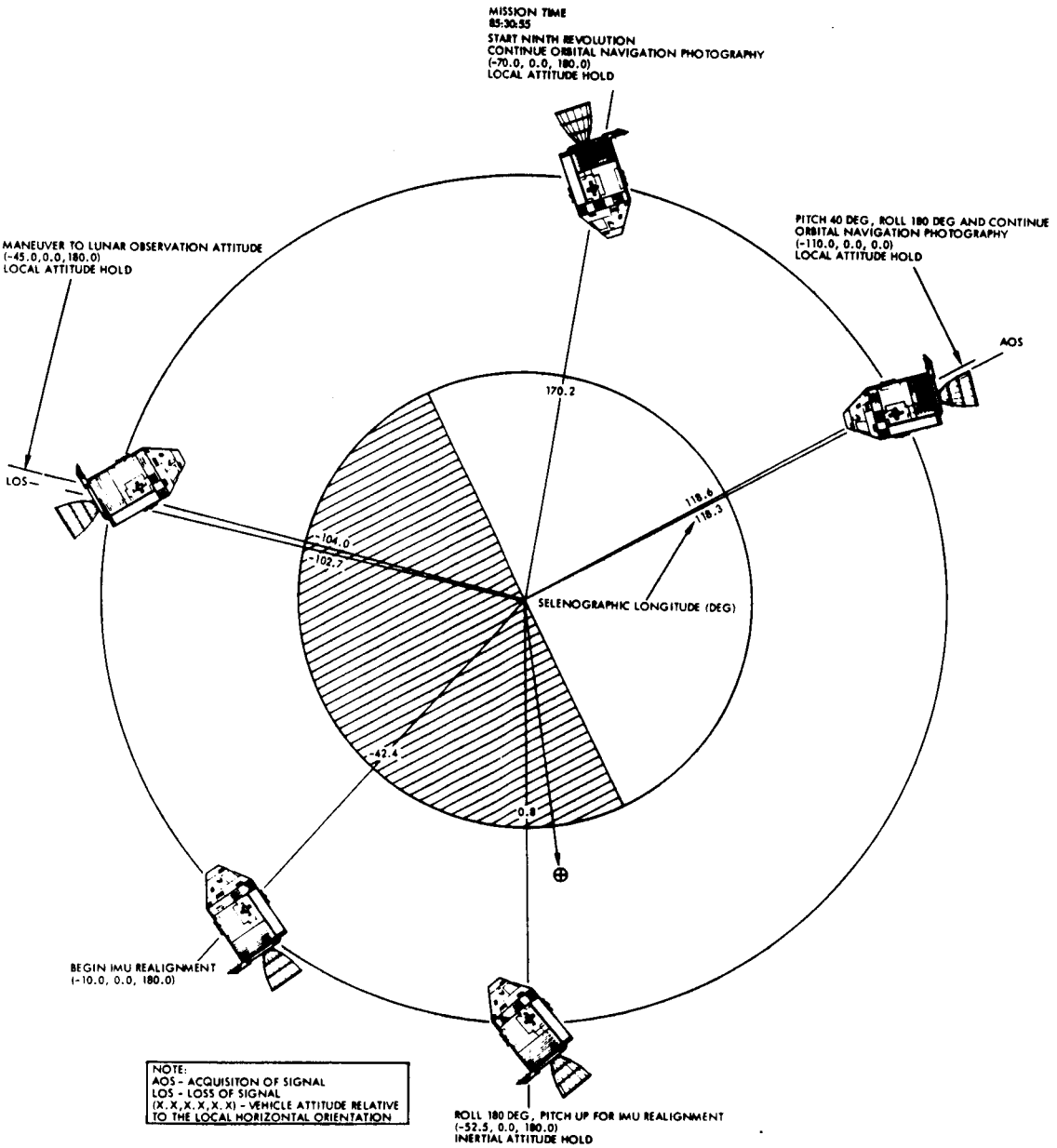


Figure 14. Ninth Revolution Major Events and Attitudes

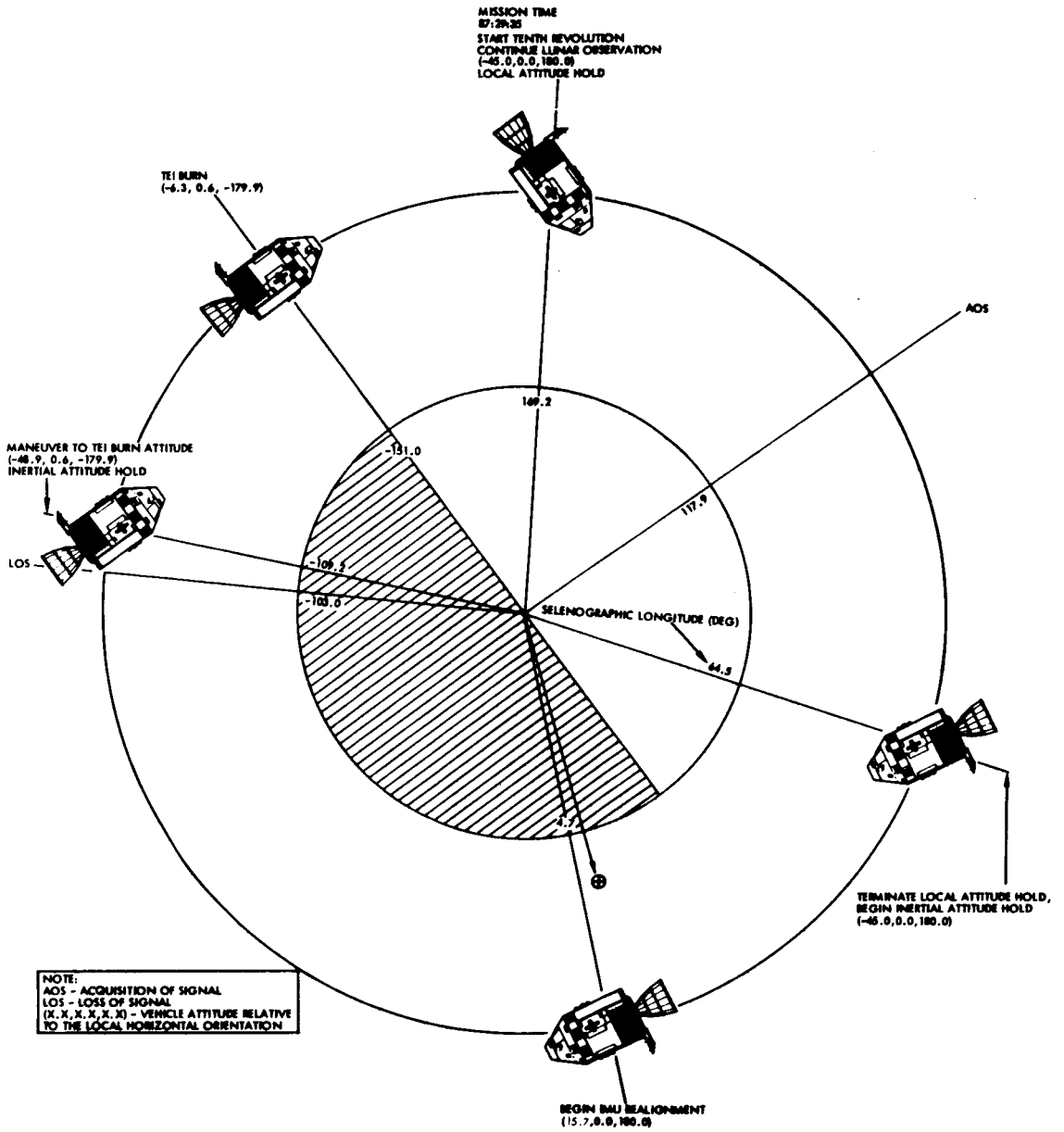


Figure 15. Tenth Revolution Major Events and Attitudes

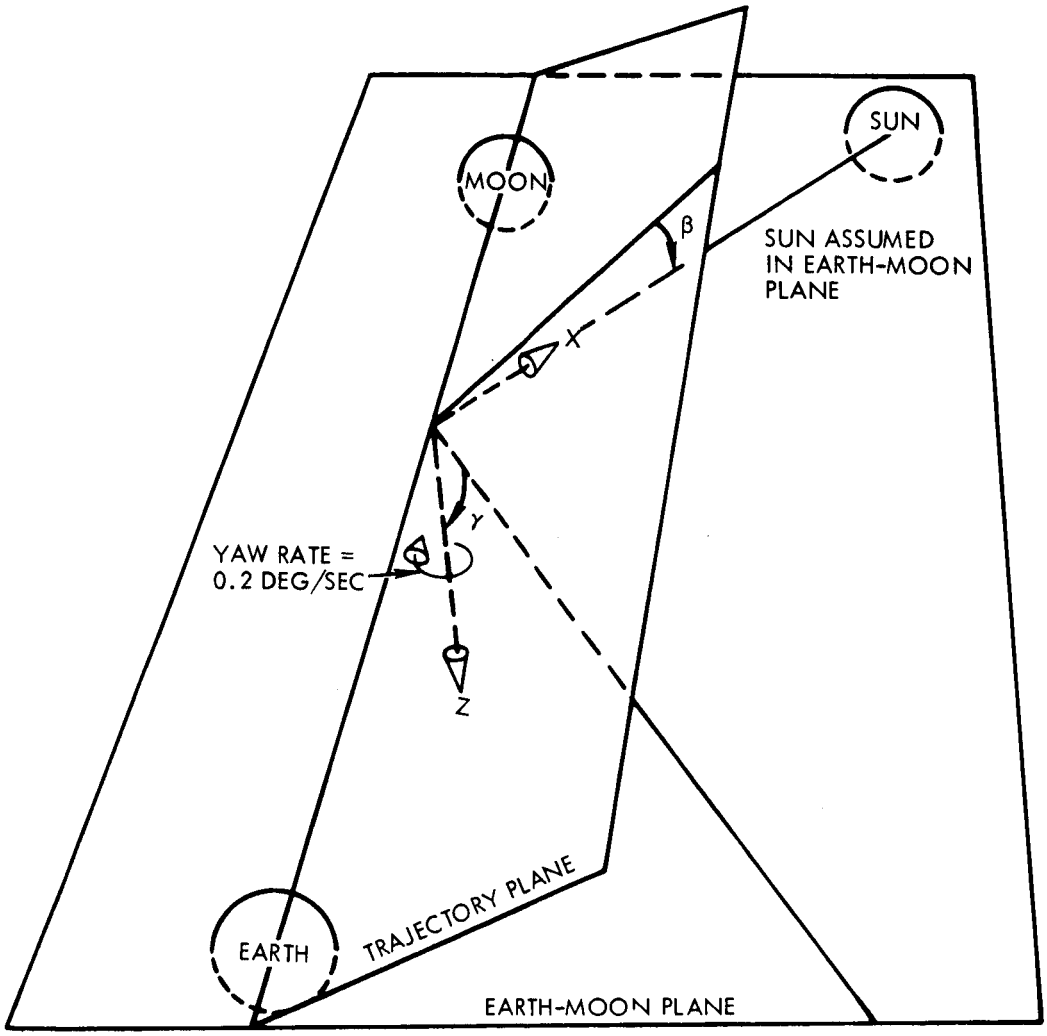


Figure 16a. PTC Tumble Mode Attitude Geometry

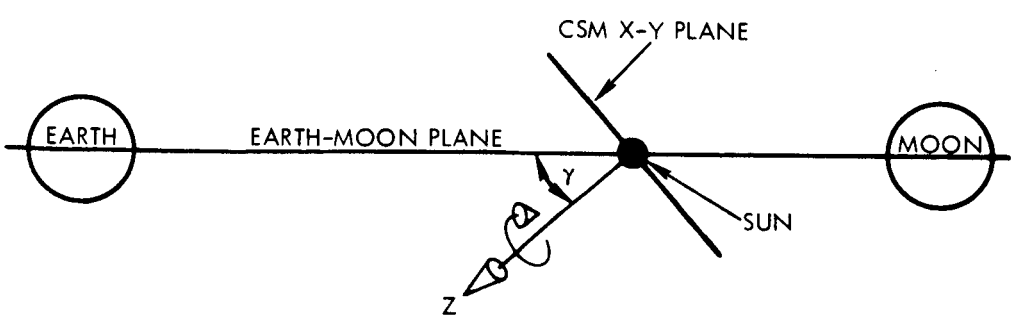


Figure 16b. PTC Tumble Mode Attitude Geometry as Viewed from the Sun

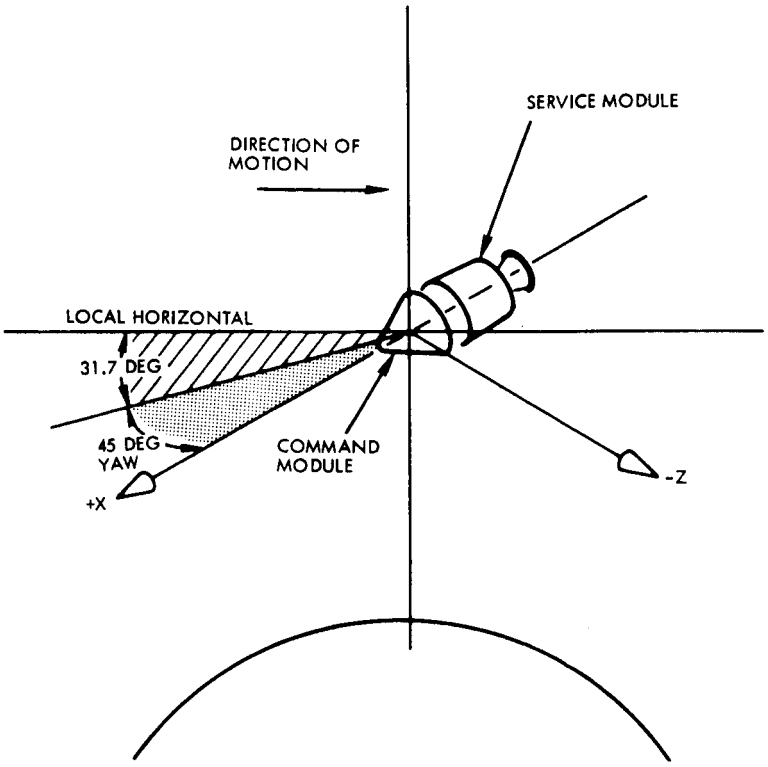


Figure 17a. CM/SM Separation Attitude

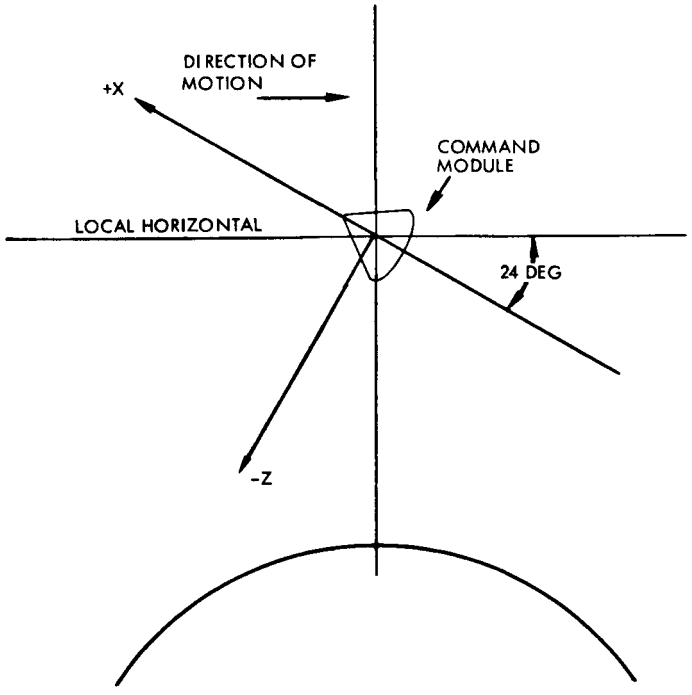


Figure 17b. CM Entry Attitude

REFERENCES

1. Preliminary Flight Plan Apollo 8. NASA MSC Document CF 342-8M-156, October 8, 1968.

2. G. W. Ricks: C'Mission Post TLI Sequence of Events. MSC Memorandum 68-FM55-303, October 7, 1968.